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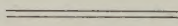
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MINERAL PARAGENESES OF SOME GRANITE PEGMATITES NEAR KRAGERØ, SOUTHERN NORWAY

BY
HARALD BJØRLYKKE

WITH 6 FIGURES IN THE TEXT

Field investigations of pegmatites near Kragerø have been carried out for several seasons; but most of the work was done in the summer of 1935 by grants given to me by the Fritjof Nansen Fund.

Some of these pegmatites had not been mined for many years and it was often very difficult, therefore, to collect complete series of the minerals. The description of the minerals of some of the dikes has therefore partly been based on a study of representative samples in the collections of the mineralogical museum in Oslo. Since some of these minerals have been bought from mineral dealers I have been very careful only to use the material whose origin seemed to be quite sure. For the photographs I am indebted to Miss Lily Monsen.

The Pegmatite at Kalstad-Lindvikskollen.

About 2 km W of Kragerø, on the hill Lindvikskollen an unusually large body of pegmatite crops out, the main part of which forms a dike about 500 m in length and 30 m wide, striking east and probably dipping about 30 degrees to the north (fig. 1).

From the main body some smaller dikes extend to the south cutting the surrounding amphibolitic rock with sharp contacts. This is the largest known granite pegmatite body in Norway. There are several feldspar quarries in it, the two most important ones being the Kalstad feldspar mine in the eastern part and the Lindvikskollen feldspar mines in the western part of the pegmatite.

The main part of this large pegmatite body consists of graphic granite with but smaller areas of well segregated feldspar crystals. A considerable amount of black tourmaline occurs in this pegmatite

especially in the eastern parts. The crystals are very large (30—40 cm across), partly well developed, and usually imbedded in quartz. Both in size and in amount they exceed what is otherwise known from similar occurrences in Norway.

In the feldspar quarries at Kalstad and at Lindvikskollen the chief minerals are microcline, quartz, plagioclase, and biotite. Other minerals are muscovite, orthite, apatite, calcite, magnetite, tourmaline, ytrotitanite, ilmenite, euxenite, alvite, hellandite, and thorite. Beryl has not been found in this pegmatite. Cleavelandite with crystals of phenacite is said to occur in the Lindvikskollen feldsparmines, but when I visited these quarries no trace of cleavelandite was encountered neither in the walls of the trenches nor in the dumps. It seems likely therefore that cleavelandite only occurs in small confined parts of the pegmatite.

The mineral paragenesis of this dike has previously been described by W. C. Brøgger (7).

Microcline occurs partly as a component in graphic granite, partly in segregated crystals. Usually it is of a coarse perthitic type, reddish to yellowish in color, and according to O. Andersen (3) of the usual composition. At the Lindvikskollen well terminated crystals imbedded in quartz have been encountered.

Plagioclase is present in relatively large amounts and, like the microcline, it occurs partly in graphic granite, partly in segregated crystals. The composition corresponds to albite-oligoclase.

Biotite occurs in this pegmatite as long thin flakes, partly altered to chlorite.

Muscovite occurs very sparingly and is generally found in small leaves in plagioclase or near this mineral.

Orthite (allanite) is generally present in large ill-defined crystals in microcline. The outer shell of the mineral is regularly strongly altered and covered with a coating rich in iron oxydes. Irregular nodules without crystal outlines are also met with. It probably crystallized at approximately the same time as microcline. Orthite from this dike has previously been described by Brøgger (9). Its content of rare earth elements has been determined by Goldschmidt and Thomassen (12).

Apatite occurs characteristically in long prismatic crystals with a blue or green color, mostly imbedded in microcline. An X ray spectrogram of the mineral powder showed the presence of small amounts of rare earth elements. An apatite crystal from the collections

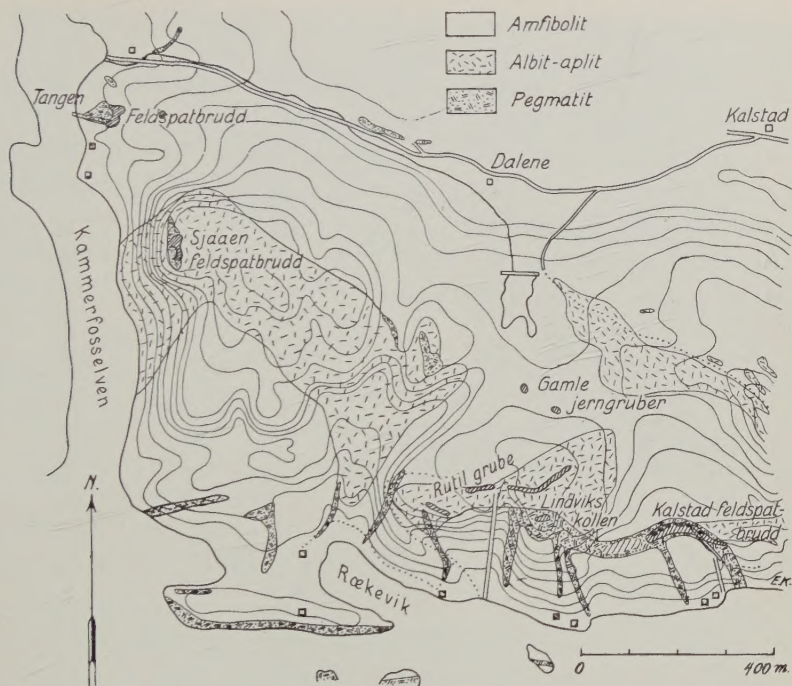


Fig. 1. Geological map of the area W of Kragerø. (Reprinted from O. Andersen: *Feltspat II. Norges Geologiske Undersøkelse Publ. 128 B*, p. 38, (fig. 14), with the permission of the director).

of the Mineralogical Museum in Oslo surrounded by small euxenite crystals shows that apatite has crystallized earlier than the euxenite.

Calcite, on a visit to the Lindvikskollen feldspar quarries in the summer of 1935 I found a few small fragments of pink calcite imbedded in microcline. The mode of occurrence strongly indicates a magmatic origin of this mineral.

Magnetite occurs frequently in small crystals and irregular nodules in the pegmatite.

Tourmaline occurs abundantly especially in the eastern part of the pegmatite. When imbedded in quartz it generally exhibits well developed crystal outlines, in microcline however it often occurs in irregular masses or just as a black coating on cracks.

Yttrotitanite is present in the pegmatite in large well developed crystals up to a weight of 3—4 kg. The crystal faces are often covered with small crystals of tourmaline.

Ilmenite occurs frequently in large but thin plates, especially in the eastern part of the pegmatite.

Euxenite occurs partly as large irregular masses and partly as smaller well defined crystals. In the wedge-shaped spaces between two plates of ilmenite meeting each other at a low angle euxenite is frequently encountered thus indicating a later time of crystallization for euxenite than for ilmenite.

As shown by an X ray spectrogram its composition is similar to that of the ordinary euxenites from granite pegmatites in Southern Norway.

Hellandite from this dike, which still is the only known occurrence of this mineral, was first found and described by Brøgger (7, 9). It is a rare silicate of the Y elements and, in agreement with the behavior of other silicates of rare earth elements, the crystallization of hellandite belongs to a late stage of the crystallization of the accessory minerals. Generally speaking it crystallized later than tourmaline although crystals of tourmaline inclosed in hellandite also have been observed.

Thorite occurs in small red colored nodules in microcline.

Tangen Feldspar Quarry.

The Tangen feldspar quarry lies on the east side of the river Kammerfosselven about 4 km W of Kragerø. The pegmatite crops out as an irregular body about 40 m in length and 10—15 m wide on the western slope of the Sjøen Mt. Only the upper boundary between the pegmatite and the surrounding amphibolite is visible (fig. 2). The western part of the pegmatite is chiefly composed of cleavelandite and quartz. But numerous irregular patches of microcline surrounded by cleavelandite are indicative of a hydrothermal replacement of an earlier magmatic microcline by cleavelandite. In the central parts of the pegmatite microcline occurs in large masses but is often cut by veins of cleavelandite.

The following minerals are met with in these dikes: microcline, quartz, oligoclase, cleavelandite, tourmaline, topaz, magnetite, hematite, apatite, yttriotitanite, orthite, alvite, thorite, betafite, columbite, and phenacite. Biotite, muscovite, and beryl have not been encountered.

Microcline of this dike is a coarse perthite rich in soda. It is translucent in parts and has a greyish color.



Fig. 2. The upper boundary between pegmatite and amphibolite.
Tangen feldspar quarry.

Quartz of the microcline pegmatite is white or transparent while the quartz which occurs together with the cleavelandite often is smoky.

Cleavelandite is a platy variety of albite and occurs in large masses and fanlike aggregates as well as in small veins in the microcline. It has been formed distinctly later than microcline which it seems to have replaced on a large scale. It is blue or colorless.

An chemical analysis of this mineral published by Andersen (2) (analyst. E. Klüver) shows a nearly pure albite composed of 96.3 % Ab, 0.9 % Or, 0.7 % An, and 2.1 % impurities.

Tourmaline occurs abundantly, partly in well developed crystals in quartz and partly in irregular masses in microcline or on cracks in this mineral. It also occurs frequently in cleavelandite.

Topaz. One specimen of topaz surrounded by cleavelandite labelled Tangen belongs to the collections of the Mineralogical Museum

in Oslo, but on my visits to the dike I have not been able to find this mineral.

Magnetite occurs in nodular masses in the microcline. An X ray spectrogram of the mineral powder shows that it contains considerable amounts of Ti and Mn.

Hematite is present in nodules in cleavelandite (fig. 5). The color is brown with a red streak. An X ray spectrogram shows that it contains Ti and Mn, but in somewhat smaller amounts than does the magnetite. The mode of occurrence and the chemical composition of this mineral indicates to me that it was formed by the action of gasses and solutions on the magmatic formed magnetite during the hydrothermal-pneumatolytic stage of the cleavelandite formation. Such secondary formed hematite has previously been described under the name of martite from Canadian pegmatites by Ellsworth (10).

Apatite of this dike is usually met with in small, green crystals.

Yttrotitanite is present in sharp edged crystals in microcline and quartz.

Orthite (allanite) occurs abundantly in irregular nodules and ill-defined crystals. X ray spectrograms of this orthite show it to contain considerable amounts of Ti.

Alvite is a very common mineral in the dike. It occurs in relatively large crystals and irregular masses, brown of color with a greyish outer zone. It crystallized partly later than the betafite. X ray spectrograms show it to contain considerable amounts of Y, Th, and U, and as first pointed out by Goldschmidt and Thomassen (13) it is also very rich in Hf.

Thorite is met with in small red colored nodules, some of them occur in betafite while others are distinctly younger than this mineral. As shown by an X ray spectrogram it is exceptionally poor in U, contains, however, small amounts of the Y-elements.

Betafite from this dike has previously been analyzed and described by me (4). It occurs both in microcline and cleavelandite. It differs from the previously described betafites by being richer in TiO_2 , the amount of which ranges from 32 % to 35 %. Minerals of the betafite group have also been found in pegmatite dikes in Iveland (4) where they with considerable certainty have been referred to the magmatic stage of formation. At Tangen the betafite which occurs encompassed by cleavelandite should therefore in my opinion be regarded as a magmatic mineral that on account of a greater power of resistance

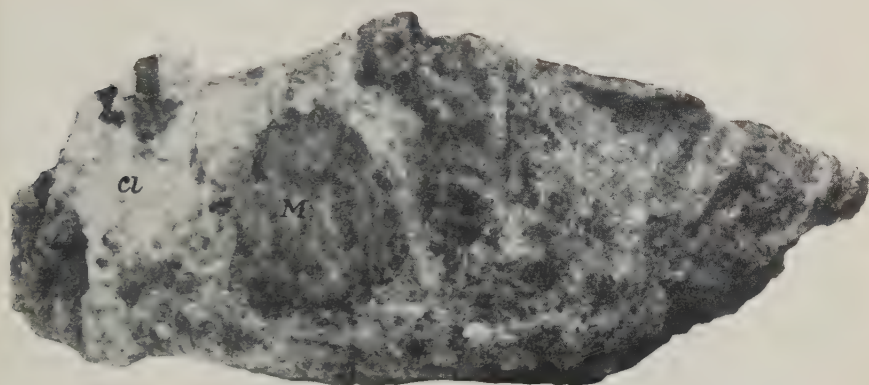


Fig. 3. Microcline (M) surrounded by metasomatic cleavelandite (Cl.).
Tangen feldspar quarry.

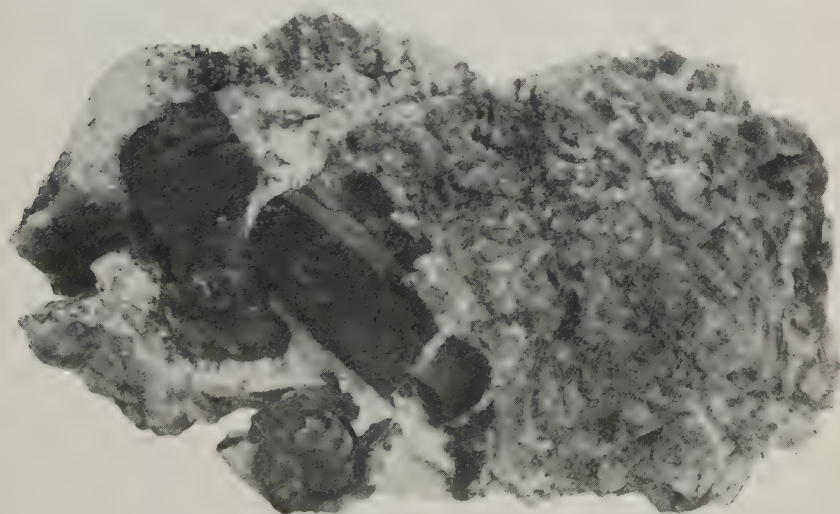


Fig. 4. Crystals of columbite in cleavelandite.
Tangen feldspar quarry.

to hydrothermal solutions was able to escape alteration, while most of the other magmatic minerals were replaced by cleavelandite and quartz. Around the nodules of betafite cleavelandite has been stained red.

Columbite is present in beautiful crystals imbedded in cleavelandite and often cut by blades of this mineral. It has not been

found in microcline. X ray spectrograms show the content of Mn to be greater than that of Fe and the mineral should therefore be characterized as *manganocolumbite*. This is insofar in accordance with what I previously have found in other Norwegian pegmatites as hydrothermal-pneumatolytic minerals generally are enriched in Mn as compared with minerals of magmatic origin.

Phenacite is present in nicely developed crystals in cleavelandite and quartz and is the only beryllium mineral in the dike. In harmony with Goldschmidt's (11) classification of phenacite as a plumasitic mineral it occurs in this pegmatite together with topaz. Muscovite has not been found in this pegmatite and thus the formation of phenacite instead of beryl may be due to a deficiency of alumina. Phenacite from this dike has been analyzed by Andersen-Aars (1).

Obviously the granite pegmatite dike at Tangen has been formed in two epochs, one magmatic and one hydrothermal-pneumatolytic. It belongs therefore to the type of pegmatites that Landes (15) calls complex pegmatites.

The magmatic pegmatite is microcline pegmatite containing the following primary minerals: quartz, oligoclase, tourmaline, magnetite, apatite, yttrotitanite, orthite, alvite and betafite.

By the action of thermal solutions and gasses many of the previously formed magmatic minerals were replaced by hydrothermal-pneumatolytic material chiefly cleavelandite and quartz. Black tourmaline with the same appearance as the magmatic one was also formed during this phase. Other minerals formed by hydrothermal-pneumatolytic activity are: topaz, hematite (by alteration of magmatic magnetite?), columbite and phenacite.

Replacement origin of certain minerals in magmatic pegmatites has been contended by me in the case of several occurrences in Iveland. However, here the cleavelandite-quartz deposits form rather regular dikes and bodies with sharp boundaries against the microcline pegmatite while the occurrence at Tangen exhibits a more interdigitating association with veins and apophysae of cleavelandite cutting through crystals of microcline. It looks as if the magmatic pegmatite at Tangen once became subjected to intense shearing and cracking with consequent facilitating the injection and interpenetration of the secondary gases and solutions.



Fig. 5. Nodules of hematite in cleavelandite.
Tangen feldspar quarry.

Sjåen Feldspar Quarry.

At the top of the mountain Sjåen at Tangen a granite pegmatite crops out on the face of a cliff in the shape of a rather irregular body surrounded by albite aplite (Kragerite). It is about 100 m in length and 20—30 m broad.

The main part of the pegmatite consists of well segregated large crystals of feldspar and quartz, but it is also rich in graphic granite. The microcline is penetrated by a large number of dikes, veins, and irregular bodies of cleavelandite and quartz of metasomatic origin. The pegmatite is strikingly similar to that at Tangen and is obviously formed in the same way.

The minerals of this pegmatite are: microcline, quartz, plagioclase, cleavelandite, tourmaline, magnetite, yttrotitanite, orthite, and

betafite. Other than these minerals large crystals of green pyroxen frequently occur.

On many of the islands south of Kragerø granite pegmatites have been opened for feldspar production. These feldspar quarries have been previously described by Andersen (2, 3).

It is worthy of notice that some of these pegmatites contain plagioclase as the chief feldspar with but lesser amounts of microcline. Some dikes also contain calcite of magmatic origin. This is for instance the case with a plagioclase pegmatite dike rather rich in red colored calcite on the island Risø. The microcline of these dikes is red and seems to be of the ordinary type. However, the pegmatites on the islands south of Kragerø are very poor in rare minerals, thus no niobate or tantalate minerals have been found in them. Nor has any cleavelandite-quartz phase been observed. Common accessories are tourmaline and titanite.

The pegmatite dikes in the neighbourhood of Kragerø, in spite of marked difference between them, yet seem to exhibit many similar features that distinguish them from the granite pegmatites in other parts of Norway.

A most striking feature is for instance the plenitude of Ca as indicated by the presence of calcite and of the Ca-bearing, rare minerals, hellandite, titanite, and betafite. As previously pointed out by me (6) the presence of apatite in granite pegmatites containing silicates of the rare earths also indicates sufficiency in Ca. In dikes deficient in Ca phosphorous and the rare earth elements will react with formation of monazite and xenotime. Under magmatic conditions the combination of orthite and apatite obviously becomes unstable if the Ca-content drops under a certain value. With decreasing amounts of Ca the following reaction thus will take place:



Another characteristic feature of the pegmatites of this area is the abundance of tourmaline.

As explained in a previous paper (6) by me, the granite pegmatites of Iveland may be divided into two main groups: *I. Pegmatites poor in Ca, and II. Pegmatites rich in Ca.*

In Iveland more than 100 of the pegmatites studied could be referred to the first group, and only 5 to the second group. The pegmatites belonging to group II were characterized by:

1. The occurrence of Ca-rich niobates, tantalates, and titanates of the pyrochlore group such as betafite, or the titanosilicate titanite.
2. Apatite occurring frequently.
3. The dikes usually being rich in plagioclase feldspar.

The mineral assemblage of the Ca-rich pegmatites of Iveland thus is analogous to that of the magmatic pegmatites near Kragerø.

The magmatic and the hydrothermal-pneumatolytic deposits at Tangen represent two different mineral parageneses which do not seem to be in equilibrium with each another, the same was the case in the complex pegmatite dikes in Iveland. The columbite of the cleavelandite pegmatite for example is probably unstable together with the Yttrium-bearing silicates, hellandite, and yttrotitanite of the magmatic pegmatites. In Iveland the cleavelandite-quartz pegmatites are enriched in Ta as compared with the magmatic pegmatites and contain microlite and tantalite very poor in Nb. At Tangen the characteristic niobate-tantalate mineral of the cleavelandite-quartz pegmatite is columbite which does not seem to differ from the magmatic columbites of the Norwegian pegmatites in its proportion Nb : Ta. However, as distinct from the magmatic columbites it does show a high ratio Mn : Fe and may properly be called a mangano-columbite.

In columbite from Katterås, Iveland about the same high ratio Mn : Fe is encountered. This columbite occurs in cleavelandite and seems to have been formed therefore during the hydrothermal-pneumatolytic phase. In tantalites from cleavelandites pegmatites at Landås and at Skripeland in Iveland the ratio Mn : Fe is also greater than in magmatic columbites.

From X ray spectrograms of a great number of columbites and tantalites from Norwegian granite pegmatites it can be deduced that the ratio Mn : Fe ranges from 1 : 6 to 1 : 2 in the magmatic minerals, while columbites and tantalites of the cleavelandite pegmatites, have a ratio Mn : Fe about 2 : 1 for the columbites, and near 1 : 1 for the tantalites.

Beryllium in the magmatic phase is conspicuous by its absence in the dikes near Kragerø. Such Ca-rich granite pegmatites containing rare minerals but without beryllium have not been described from any other parts of Norway.

In the pegmatite at Kalstad-Lindvikskollen the relative amount of the Y-elements is large as compared with the amounts of Nb and

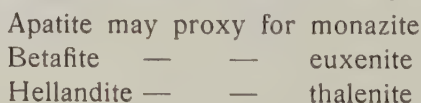
Ta; the excess yttrium has here formed the silicate hellandite. In my paper on the Iveland pegmatites I pointed to the fact that the formation of yttriumsilicates is possible only if the pegmatite contain a surplus of the yttrium elements over the combined amounts of Nb and Ta.

In pegmatites poor in Ca the yttrium silicate thalenite results if no or insufficient beryllium is present in the magma as first pointed out by Schetelig (16). But in beryl-bearing dikes the yttrium-beryllium-silicate, gadolinite, is the stable mineral. Thus beryl and thalenite can not occur together in the same pegmatite but react according to following scheme:



The mineral paragenesis of the Ca-rich granite pegmatites of Iveland (table I) indicates that gadolinite is the stable Y-silicate in presence of Be. The paragenesis of the Ca-rich pegmatite at Kalstad-Lindvikskollen shows that thalenite is not stable in this pegmatite in spite of the absence of Be, but that the Ca-Y-silicate, hellandite, has formed instead.

Thus hellandite seems to substitute for thalenite much in the same way as the Ca-bearing niobate, betafite, partially substitutes for euxenite in some places. Thus certain minerals of the granite pegmatites may become unstable if much Ca is present, and be replaced by Ca-bearing minerals of similar composition:



The mineral parageneses of the Iveland and Kragerø pegmatites further indicate that hellandite like thalenite is unstable together with beryl. Thus following reaction holds:



Thus gadolinite will be the stable Y-silicate of the Ca-rich dikes if sufficient beryllium is present and hellandite if beryllium is deficient. Therefore I have called the Y-silicate bearing Ca-rich granite pegmatites the *hellandite-gadolinite type*. It constitutes an analogue to the thalenite-gadolinite type of the pegmatites poor in Ca. Other characteristic minerals of the pegmatites belonging to the hellandite-gadolinite type are betafite, yttrotitanite, and apatite.

Table 1.

The mineral parageneses of the Ca-rich granite pegmatites of the Iveland and Kragerø area.

	Iveland and Evje					Kragerø		
	Rosås 4	Birketveit 1	Ljosland 10	Ljosland 11	Landsverk	Tangen	Kalstad	Høgsjåen
Microcline.....	x	x	x	x	x	x	x	x
Quartz.....	x	x	x	x	x	x	x	x
Plagioclase.....	x	x	x	x	x	x	x	x
Biotite.....	x	x	x	x	x	.	x	.
Muscovite.....	x	x	x	x	x	.	x	.
Garnet.....	x	.	.	.	x	.	.	.
Tourmaline.....	.	.	.	.	.	x	x	x
Beryl.....	x	.	.	x	x	.	.	.
Gadolinite.....	.	.	.	.	.	.	.	.
Hellandite.....	.	.	.	.	.	.	x	.
Orthite.....	.	x	.	.	x	x	x	x
Alvite.....	.	.	.	.	.	.	x	.
Yttrantalite.....	x	.	.	x	.	.	.	.
Fergusonite.....	.	.	.	.	x	.	.	.
Yttritanite.....	.	x	x	.	.	x	x	x
Euxenite group.....	.	x	x	x	x	.	x	.
Betafite.....	.	.	x	.	x	x	.	x
Ilmenite.....	.	.	.	.	.	.	x	.
Magnetite.....	.	.	.	.	.	.	x	x
Thorite.....	.	x	.	.	x	x	x	.
Monazite.....	.	.	x	.	.	.	.	.
Xenotime.....	.	x	x	.	x	.	.	.
Apatite.....	.	?	x	x	x	x	x	.
Chalcopyrite.....	.	.	x	.	.	.	.	.
Chalcocite.....	.	.	.	.	.	.	.	.
Calcite.....	.	.	.	x	.	x	.	.

The granite pegmatite at Landsverk, Evje, contains calcite, apatite, and betafite and is therefore relatively rich in Ca. It also contains fergusonite but no Y-silicate minerals have been encountered. Thus this dike represents a third type of Ca-rich pegmatites which I have called the *fergusonite-betafite type*. The fergusonite is obviously a stable mineral also when the pegmatite is relatively rich in Ca. Parallel to the euxenite type is the *betafite type* in which neither Y-silicates nor Y-orthoniobates are present, the characteristic mineral being the metaniobate, betafite.

My earlier classification of the Ca-poor pegmatites of Iveland has therefore now received its counterpart in an analogous classification of the pegmatites rich in calcium:

I. *Pegmatites poor in Ca.*

1. Thalenite-gadolinite type.
2. Fergusonite type.
3. Euxenite (samarskite) type.
4. Columbite type.

II. *Pegmatites rich in Ca.*

1. Hellandite-gadolinite type.
2. Fergusonite-betafite type.
3. Betafite type.

In the Gjerstad district North of Kragerø additional granite pegmatites have been mined for feldspar and beryl. The mineral parageneses of these dikes exhibit some differences from those of the granite pegmatites of the area around Kragerø. However, the abundant occurrence of black tourmaline in the pegmatites of both areas makes a genetic relation probable. Most of the dikes in this area contain heryl.

On the top of the hill Mørkhøgda in the northern parts of Gjerstad a few shots have been put in a pegmatite dike in search for beryl. The exposed part of the pegmatite consists of cleavelandite and quartz with large crystals of black tourmaline. A yellow or green beryl, without crystal outlines was present in masses up to 20 cm in diameter (fig. 6). Small crystals of fergusonite were imbedded in the beryl, thus indicating that the beryl is of magmatic origin and has partly resisted the later hydrothermal-pneumatolytic alteration. Cleavelandite also contains minute ill-defined crystals and lense-shaped nodules of microlite about 1 mm in diameter. X ray spectrograms of the microlite showed it to be a nearly pure tantalate with a composition almost identical to that of the microlite previously described from Iveland (5).

Other minerals in this pegmatite were euxenite, alvite in small needle-shaped crystals, red, translucent spessartite in plates and ill-defined crystals, and white and lilac muscovite. Undecomposed microcline pegmatite was not seen in the exposed parts of the dike. With the exception of tourmaline the mineral assemblage of this dike is very similar to that of the microlite and tantalite-bearing dikes previously described from Landås and skripeland in Iveland (6).

On the property of the farm Brokeland S. Gjerstad about 300 m N of the main road a small pegmatite dike has been mined

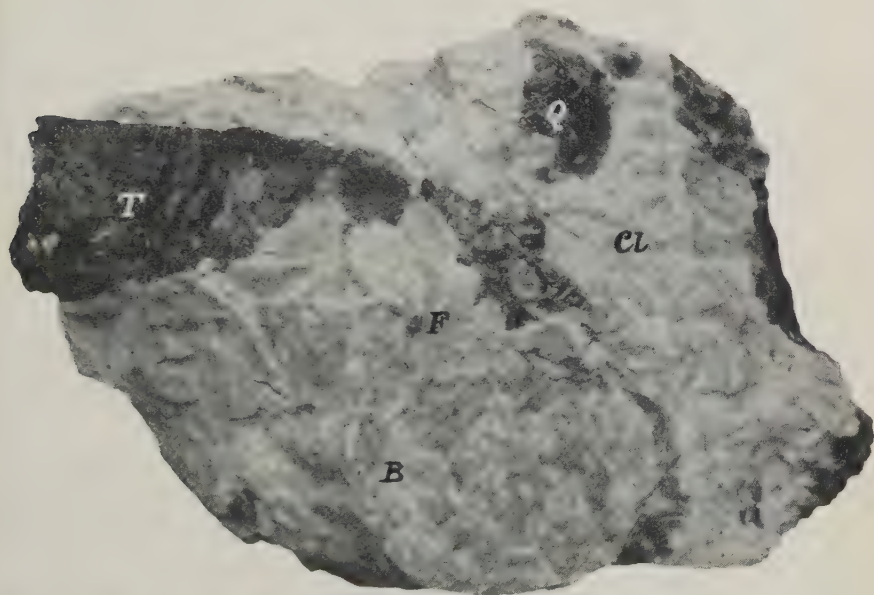


Fig. 6. Tourmaline (T), beryl (B) with inclosed crystal of fergusonite (F), quartz (Q), and Cleavelandite (C). The pegmatite at Mørkhøiden, Gjerstad.

for feldspar. The pegmatite was of the ordinary microcline type and contained the following minerals: microcline, quartz, plagioclase, biotite, muscovite, garnet, black tourmaline, beryl, and columbite. The magmatic origin of the columbite is verified by a low ratio $Mn:Fe$, as shown by an X ray spectrogram.

At Hulleknatten on the property of the fram Brenndalsmo in Gjerstad, a small pegmatite dike has been opened by a few shots in search for beryl. The chief minerals of the dike are white microcline, plagioclase, biotite, muscovite, and beryl. Other minerals were spessartite and columbite. Only about 250 kgms beryl has been produced. The microcline contained small blades of sericite and had therefore no commercial value. An X ray spectrogram showed that considerable amounts of tungsten were present in the columbite.

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ON ROSENBUSCHITE

BY

M. A. PEACOCK

WITH 3 FIGURES

Rosenbuschite is one of the numerous mineral species named by Brøgger (1887) and described in full detail in his great work on the minerals of the syenite-pegmatites of southern Norway (1890). This rare mineral occurs in sparse pale-orange patches of close-packed parallel to divergent fibres and needles embedded in coarsely crystallized pegmatite at Langesundsfjord. From the straight extinction of the fibres and such meagre goniometric measurements as were possible on this unfavourable material, Brøgger concluded that rosenbuschite is monoclinic, elongated with the symmetry axis. Taking the plane of cleavage parallel to the needle-axis as the base, and naming the observed forms $c\{001\}$, $a\{100\}$, $s\{\bar{2}01\}$, $h\{540\}$, Brøgger obtained geometrical elements somewhat similar to the accepted monoclinic elements of pectolite and wollastonite. Analyses on limited material revealed a complex composition which Brøgger interpreted as essentially a fluo-silicate, zirconate and titanate of lime and soda, of metasilicate type. These crystallographic and chemical findings appeared to form a firm basis for accepting rosenbuschite as a zircon-pectolite and appending it to the wollastonite group, which was regarded as a part of the wider group of the pyroxenes. Since the appearance of Brøgger's work no direct observations on rosenbuschite have been recorded.

Recent studies on unusually well-developed crystals of wollastonite (author, 1935 A) and pectolite (author, 1935 B) led in both cases to triclinic elements directly comparable to the elements of the structure lattices of these minerals previously determined by Warren and Bischof (1931). The absolute lattice elements of the two minerals are nearly alike; and in both cases the classical monoclinic lattices are related to the proper triclinic lattices in such a manner that the important vertical planes with the improbable symbols (140) and (540)

in the monoclinic lattices receive the natural symbols (010) and (110), respectively, in the triclinic lattices, while the symbols in the common main zone [010] remain unchanged. Since schizolite and vogtite were already known to be triclinic with lattice elements similar to the newly determined elements of wollastonite and pectolite, the wollastonite group proved to be a group of homeomorphous triclinic minerals to which rosenbuschite presumable also belonged.

In view of the analogy which Brøgger had established between rosenbuschite and pectolite, the writer considered it probable that the only known plane cutting the needle-axis of rosenbuschite, namely h (540) in the monoclinic lattice, was in reality m (110) in a triclinic lattice, as had proved to be the case in wollastonite and pectolite. On this assumption he computed triclinic elements for rosenbuschite which seemed more probable than the original monoclinic axial ratio. These triclinic elements, which compare roughly with those of wollastonite, were given in both the studies mentioned, in which rosenbuschite is tentatively retained in the wollastonite group pending further investigation.

The symmetry of rosenbuschite was first directly determined at the Geophysical Laboratory in Washington, by Professor T. F. W. Barth and Mr. C. J. Ksanda who kindly undertook to make X-ray measurements on a minute needle from a specimen from Langesundsfjord. In a private communication Dr. Barth reported that rosenbuschite is triclinic with elements which proved to be roughly proportional to those computed by the present writer; but that the presence of two unaccounted spots on the weak equator Weissenberg photograph indicated a true unit cell larger than that defined by these parameters.

Further X-ray study with a larger crystal was clearly necessary to obtain a satisfactory determination of the structural lattice of rosenbuschite; and since the available material failed to yield a suitable crystal, Dr. Barth requested Dr. I. W. Oftedal of the Mineralogical and Geological Museum of the University in Oslo to supply a suitable specimen. Dr. Oftedal promptly responded with a handsome specimen from Skutesundskjær, Langesundsfjord, Norway, from which Dr. Berman skillfully detached a single needle of sufficient thickness to give X-ray photographs of the desired intensity. On this crystal the writer determined the structural lattice of rosenbuschite during a recent visit to the Geophysical Laboratory in Washington. He is

grateful to Dr. Oftedal for supplying suitable material, to Mr. Ksanda for preparing the X-ray photographs, to Dr. Barth and Dr. Tunell for assistance in discussing the results, to Dr. Day for permission to work in the Laboratory, to Professor Palache for facilitating the visit to Washington, and to Dr. Berman for advice on the classification of rosenbuschite.

Morphology.

On the newly acquired specimen from Langesundsford rosenbuschite presents the described appearance. The longitudinal cleavage planes of the needles are easily distinguished from vitreous random lengthwise fractures. Groups of divergent needles are also traversed by subparallel fractures cutting the needle axes obliquely. It was thought that these fractures might represent a cleavage after a rational plane; but later optical study showed that the fractures are not constant in their inclination to the needle-axes although their surfaces are tolerably plane. Ferruginous films in the transverse fractures, and to some extent between adjacent needles, seem to account for most of the pale orange colour of the aggregates. A true body colour is barely perceptible in single needles; fragments suitable for optical study are almost colourless and perfectly transparent.

The fragment detached for crystallographic study was part of a single crystal; it was about 1.0 mm long and 0.3 mm in greatest width with five measurable faces representing three forms, including the cleavage, in the zone of the needle-axis. Both ends of the fragment were formed by broken surfaces. On the reflecting goniometer the parallel opposite cleavage surfaces gave fair reflections; the remaining faces gave only feeble and blurred images. Table 1 gives the measured angles and the corresponding angles calculated from the later determined elements of the structural lattice; Brøgger's measured angles, suitably reduced, are added for comparison.

Table 1.
Rosenbuschite: Interfacial Angles.

Peacock	Measured	Calculated	Brøgger	Measured
$a(100) : b(010) = 68^\circ 33'$	68 07	$67^\circ 30'$	$c(001) : s(\bar{2}01) = 67^\circ 39'$	67 32
				67 02
				70 26
$a(100) : n(\bar{1}20) = 76^\circ 11'$	76 06	$78^\circ 30\frac{1}{2}'$	$c(001) : a(100) = 78^\circ 13'$	78 04

The calculated values agree sufficiently well with the measurements of Brøgger, who evidently succeeded in isolating a better developed crystal than the one on which our indifferent goniometric readings were obtained. The agreement between the new measurements and the calculated angles is poor, yet good enough to confirm Brøgger's three forms in the zone of the needle-axis, $a\{100\}$, $c\{001\}$ cleavage, $s\{201\}$, which become $n\{1\bar{2}0\}$, $a\{100\}$ cleavage, $b\{010\}$, respectively, in the adopted setting. The material studied showed no end-planes and therefore there is no prospect of obtaining morphological elements. Brøgger's remaining form, $h\{540\}$, was based on a single face which Brøgger first regarded as a contact face but later accepted as a rational plane since it gave an axial ratio similar to that of pectolite. The position of $h\{540\}$, as defined by Brøgger's elements, proves, however, to be highly complex in the reciprocal structural lattice; this shows that the plane on which it was based was, after all, a random surface. From this it follows that Brøgger's axial ratio, and consequently the present writer's previously given triclinic elements, are partly erroneous.

As will appear later, rosenbuschite is less closely related to the wollastonite group than was formerly supposed. I have therefore abandoned the unconventional setting of the species, in which the axis of the main zone was taken as $[010]$, and have adopted the "normal triclinic setting", as recently defined (1937). In this setting the morphological elements correspond to the simple cell whose edges are the three shortest non-coplanar identity periods in the structural lattice; and the orientation of this cell is the one out of twenty-four positions in which the axis of morphological elongation is $[001]$, the basal plane (001) slopes to the front and to the right (α and β both obtuse), and $b[010]$ is greater than $a[100]$. In this setting the cleavage becomes $\{100\}$ and Brøgger's forms in the main zone receive the symbols already given.

Structural Lattice.

The X-ray measurements were made on a Weissenberg X-ray goniometer, with certain improvements described by Dr. Tunell in a paper by the present writer (1937). The method used was one which gives a rigorous determination of the six lattice elements even when only one zone axis is recognizable on the crystal. A rotation photograph about the needle-axis gave c_0 , the identity period in that axis;

a zero-layer Weissenberg photograph gave d_{100} and d_{010} , the spacings of the two sets of planes with the greatest spacings in the zone [001], and γ^* , the reciprocal axial angle included by their normals; and a first-layer Weissenberg photograph gave the horizontal off-set of the first layer of the reciprocal lattice with respect to the zero layer, measured by rectangular co-ordinates, x , y , which are functions of the reciprocal axial angles, α^* , β^* . The lengths x , y , were measured in millimeters on a projection in which the radius of the sphere of reflection is 100 mm, with reference to rectangular axes, the positive Y -axis being directed normal to (100), with the positive X -axis directed to the right (Fig. 1).¹

Excellent photographs were obtained with copper radiation which gave four serviceable layer lines in the rotation photograph and up to eleven orders of diffraction from the widest-spaced planes in the Weissenberg photographs. The zero and second layer-lines are strong; the first, third, and fourth layer-lines are weak. Before finally fixing the lattice parameters further Weissenberg photographs were taken of the second and fourth layers, to make sure that all the spots could be taken into account.²

Table 2.

Rosenbuschite: Lattice constants.

$c_0 = 7.27 \pm 0.05 \text{ \AA}$	$a^* = 0.1669$	$a_0 = 10.12 \text{ \AA}$
$d_{100} = 9.22 \pm 0.02 \text{ \AA}$	$b^* = 0.1463$	$b_0 = 11.39 \text{ \AA}$
$d_{010} = 10.52 \pm 0.03 \text{ \AA}$	$c^* = 0.2157$	$c_0 = 7.27 \text{ \AA}$
$\gamma^* = 67^\circ 30' \pm 10'$	$\alpha^* = 84^\circ 36'$	$\alpha = 91^\circ 21'$
$x = 0.5 \pm 0.3 \text{ mm}$	$\beta^* = 79^\circ 02\frac{1}{2}'$	$\beta = 99^\circ 38\frac{1}{2}'$
$y = 4.1 \pm 0.3 \text{ mm}$	$\gamma^* = 67^\circ 30'$	$\gamma = 111^\circ 54\frac{1}{2}'$

The constants in Table 2 define the structural lattice of rosenbuschite in the normal setting. The first column gives the values obtained from the X -ray photographs; the second and third columns

- ¹ This unusual choice of reference axes is due to the fact that the projections were treated as "second permutation" (as defined by the writer, 1936) projections of a triclinic crystal elongated with [010]. Normally the positive Y -axis is directed to the right, normal to (010), the positive X -axis to the front.
- ² The Weissenberg photographs showed systematically weak spots which had almost all failed to appear on the pictures previously taken by Barth and Ksanda. The present study thus proves, as surmised by Barth and Ksanda, that their provisional lattice cell was a submultiple (half) of the real unit cell.

give the corresponding calculated elements of the reciprocal and direct lattices. These have been calculated exactly, for the sake of internal consistency¹; they are of course subject to a probable error dependent on the probable errors of the experimental values. None of the elements is subject to considerable error except the angles α^* , β^* , and α , β , which are mainly dependent on the small quantities x , y , and z , and may, therefore, be in error up to one degree.

The above absolute lattice constants give the following geometrical elements of the reciprocal and direct lattices:

$$p_0 : q_0 : r_0 = 0.7739 : 0.6783 : 1; \lambda = 84^\circ 36', \mu = 79^\circ 02\frac{1}{2}', \nu = 67^\circ 30' \\ a : b : c = 0.8887 : 1 : 0.6383; \alpha = 91^\circ 21', \beta = 99^\circ 38\frac{1}{2}', \gamma = 111^\circ 54\frac{1}{2}'$$

Since one of the axial angles of the direct lattice, namely α , is nearly a right-angle, rosenbuschite belongs to the diclinic syngony of Fedorov, which comprises a considerable number of anorthic species (axinite, kyanite, wollastonite, pectolite, and others). Although diclinic lattices cannot be systematically separated from triclinic lattices on the basis of symmetry, the frequent occurrence of lattices with only two oblique axial angles remains an interesting fact which calls for a structural explanation.

The lattice of rosenbuschite possesses a further peculiarity which is expressed in the reciprocal lattice projection (Fig. 1) by the fact that the point (001) is horizontally displaced from the center, nearly in the direction of the a^* -axis by an amount which is nearly one-fourth of the a^* -period. This means, in effect, that one-fourth of the direct lattice points lie on a quadruple lattice which has two axial angles of nearly 90° and is therefore pseudo-monoclinic in character. The relations in the direct lattice are shown in Fig. 2 which represents four cells of the triclinic lattice, in full lines, and one cell of the quadruple pseudo-monoclinic lattice, in broken lines. The two lattices have the rows [010] and [001] and the planes (100) and (010) in common. In the pseudo-monoclinic cell the axial angles α , β , are nearly right-angles and [001] is the axis of two-fold pseudo-symmetry. The lattices of all the members of the wollastonite group possess this same peculiarity, which gains significance in the fact that the axis of monoclinic pseudo-symmetry, which is [010] in the

¹ The writer is obliged to Dr. George Tunell for verifying a part of these calculations.

members of the wollastonite group, in each case nearly coincides with a principal optical direction.

In regard to the relations of the proportions of the structural lattice to morphological development, it will be seen that the shortest lattice period is the direction of morphological elongation, as is commonly the case. On the other hand, the cleavage {100} follows the second greatest lattice spacing, whereas the lattice planes with the greatest spacing are usually the planes of weakest cohesion.

Optics.

Brøgger (1890, p. 380) obtained the following optical data on rosenbuschite; the orientation referring to the monoclinic axes: $X=b[010]$ (needle-axis), $Z:c[001]$ about 12° to 14° in the acute angle β ; birefringence strong; $2V$ large; sign uncertain, probably negative; body colour, light orange-gray; pleochroism very weak; absorption $Z>X>Y$. Observations on the universal stage partly confirm Brøgger's findings and partly correct and amplify them.

As Brøgger stated, one of the principal axes of the optical ellipsoid, namely X , is sensibly coincident with the needle-axis, $c[001]$ in our notation; the direction of least optical retardation is thus the direction of the shortest lattice period. Z is inclined to the normal to the cleavage, $a(100)$, at $28\frac{1}{2}'$ nearly in the acute axial angle γ . This orientation agrees fairly well with Brøgger's data, when transformed to the new lattice; it is pseudo-monoclinic in nature since one ellipsoid axis lies in a crystallographic axis which is the axis of two-fold pseudo-symmetry of the pseudo-monoclinic quadruple lattice cell. Geometrical and optical pseudo-symmetry are often associated; here we have the interesting case, also exemplified in the wollastonite group, of optical orientation apparently controlled by the pseudo-symmetry of a quadruple cell.

Directly measured in sodium light $2V$ is 78° about Z as the acute bisectrix; the optic sign is thus positive, contrary to Brøgger's conjecture. The dispersion of the optic axes is weak, $r>\nu$. A body colour is barely perceptible; and since Brøgger's absorption formula does not agree with the effects described in his text the pleochroism of rosenbuschite may be neglected as insensible.

The new optical observations on rosenbuschite are summarized below, the co-ordinate angles φ , ρ , of the ellipsoid axes, X , Y , Z ,

referring to [001] as pole and the vertical great circle through (010) as prime meridian. The orientation is shown in stereographic projection in Fig. 3, which also shows the known forms of rosenbuschite and the relations of the axial angles of the reciprocal lattice, α^* , β^* , γ^* , and of the direct lattice, α , β , γ .

	φ	ρ	$n(\text{Na})$	
X (palest orange gray)	—	0°	1.678	} ± 0.002 Positive 2 $V=78^\circ$ $r > v$ weak
Y " " "	129°	90	1.687	
Z " " "	39	90	1.705	

Atomic Content of the Unit Cell.

The existing knowledge of the chemistry of rosenbuschite rests on three analyses given by Brøgger (1890, pp. 382—383): the first represents previously published mean values of duplicate analyses by Cleve, reporting a considerable amount of rare earths, an appreciable loss on ignition but no fluorine; the second gives a considerable proportion of fluorine which was determined by Bäckström, but only a small amount of rare earths and no ignition loss in the remainder of the analysis, which was completed by Cleve; the third is a compilation of what Cleve believed to be the best values, which differ but little from those of the second analysis. For the discussion of the cell content it seems best to consider the second analysis rather than the compiled values.

From the determined elements of the structural lattice the volume of the unit cell is $V_0=763.2$ cubic Å; the measured density is $d=3.315$ (Cleve), which is close to 3.30 (Brøgger), and is perhaps the better value since it almost certainly represents the analysed material. The molecular weight of the unit cell is $M_0=V_0 d/1.65=1533$. The analysis then gives the number of each kind of atom in the unit cell, as shown in table 3.

Considering the complexities of the case the numbers of atoms treated as structurally equivalent approach the whole numbers: 8, 4, 12, 36, with surprising closeness. Neglecting the minute amount of doubtful cerium and accepting the number of fluorine atoms as 4,

Table 3.

Rosenbuschite: Atomic Content of Unit Cell.

$$M_0 = 1533.$$

1	2	3	4	5
SiO ₂ 31.36	0.5263	8.07	Si 8.07	8.07
ZrO ₂ 20.10	0.1644	2.52	Zr 2.52	
TiO ₂ 6.85	0.0864	1.33	Ti 1.33	4.08
¹ Fe ₂ O ₃ 1.00	0.0063	0.10	Fe''' 0.20	
² Ce ₂ O ₃ 0.33	0.0010	0.015	Ce 0.03	
MnO 1.39	0.0198	0.30	Mn 0.30	12.04
CaO 24.87	0.4475	6.86	Ca 6.86	
Na ₂ O 9.93	0.1589	2.44	Na 4.88	
F 5.83	0.3093	4.74	F 4.74	36.16
O -2.45	0.1543	-2.37	O -2.37	
			33.79	
99.21				

1. Rosenbuschite, Langesundsfjord, Norway; analysts Cleve and Bäckström (Brøgger, 1890, p. 383). ¹ State of oxidation not determined. ² Reported as „Ceritoxide (?)“.
2. Molecular proportions of the oxides reduced to the sum of 100.
3. Number of molecules in the unit cell = molecular proportion $\times M_0/100$.
4. Number of atoms in the unit cell.
5. Number of atoms treated as structurally equivalent.

the cell formula of rosenbuschite is: (Na, Ca, Mn)₁₂ (Fe''', Ti, Zr)₄ Si₈O₈₂F₄ or 4 [(Na, Ca, Mn)₈ (Fe''', Ti, Zr) (SiO₄)₂F], in which Na : (Ca + Mn) approaches 1 : 2.

If zirconium and titanium are reckoned with silicon, and fluorine with oxygen, then the formula of rosenbuschite in square brackets becomes 3RSiO₈, which is that of a typical metasilicate. The formulations of Cleve (in Brøgger, 1890, p. 384), Brøgger (1890, p. 385), and the author (1935 A, p. 526; 1935 B, p. 110), are based on this grouping. If, however, zirconium and titanium are regarded as not equivalent to silicon, which is probable from structural considerations, and fluorine is taken as structurally distinct from oxygen, as it often is, then the formula of rosenbuschite, as already given, has the characteristic form of an orthosilicate, with Si : O : 1 : 4, corresponding to unconnected silica tetrahedra in the structure.

A somewhat similar conclusion was already reached by Zachariasen (1930) who derived the general formula: $R_4Si_2X_9$ or $R_4Si_2O_7(O, OH, F)_2$ for lävenite, wöhlerite, hiortdahlite and rosenbuschite, in which R represents all the cations except silicon, and X all the anions. It should be noted, however, that Zachariasen's second formula indicates Si_2O_7 as the motif of the structure while the present study suggests Si_2O_8 as the fundamental arrangement.

Systematic Relations.

The determined cell dimensions and cell content of rosenbuschite do not support the systematic relation to pectolite indicated by Brøgger. Apparently supporting the supposed relation are the following facts: rosenbuschite is triclinic and therefore comparable in symmetry with the members of the wollastonite group (wollastonite, vogtite, bustamite, pectolite, schizolite), which have triclinic lattices; like the wollastonite lattice, the lattice of rosenbuschite is of a special diclinic type in which may be drawn a pseudo-monoclinic quadruple cell whose axis of two-fold pseudo-symmetry is the direction of morphological elongation, which is the direction of the shortest identity period in the lattice and nearly the direction of a principal optical axis. The shortest identity period in rosenbuschite ($c_0 = 7.27 \text{ \AA}$) is equal to the corresponding identity period in wollastonite ($b_0 = 7.27 \text{ \AA}$) and nearly equal to that in pectolite ($b_0 = 7.08 \text{ \AA}$), as determined by Warren and Biscoe (1931). This similarity in the principal lattice periods of the three species points to a similarity in the atomic arrangements in the corresponding directions; but the lack of any further simple inter-relations of the lattice parameters indicates no further structural similarities. Furthermore, the cell formula of rosenbuschite, $(Na, Ca, Mn)_{12} (Fe''', Ti, Zr)_4 Si_8 O_{32} F_4$, is quite dissimilar from that of pectolite, $Na_2 Ca_4 Si_6 O_{16} (OH)_2$, and wollastonite, $Ca_6 Si_6 O_{18}$, found by Warren and Biscoe (1931). There is thus no good ground for retaining rosenbuschite in the wollastonite group, as Zachariasen already concluded from general structural considerations.

In a forthcoming structural classification of the silicates Dr. Berman has formulated and arranged a number of silicates with essential zirconium in a "Wöhlerite Family" which he treats as a division of the "Normal Orthosilicates" having the structural motif (SiO_4). The writer has had the privilege of reading Dr. Berman's essay in manuscript, from which the following presentation is abstracted with slight

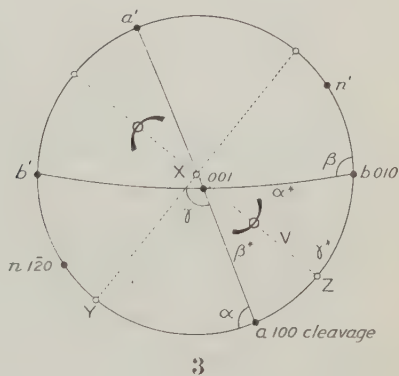
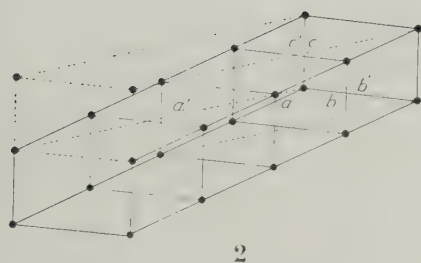
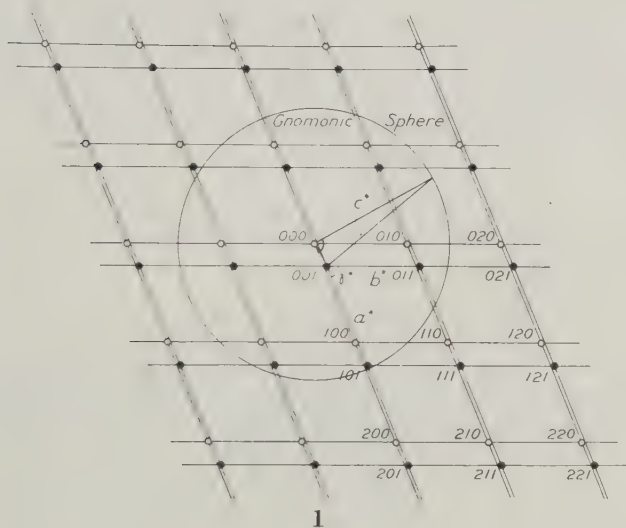


Fig. 1. Rosenbuschite: projection of the zero- and first layers of the reciprocal structural lattice on the plane normal to [001].

Fig. 2. Rosenbuschite: inclined view of the direct structural lattice, showing four unit cells (full lines) and one quadruple cell (broken lines) which is pseudo-monoclinic with [001] as the axis of two-fold pseudo-symmetry.

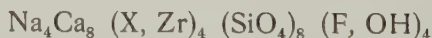
Fig. 3. Rosenbuschite: stereographic projection showing the relation of the principal optical directions, X , Y , Z , and the optic axes (with brushes) to the axial planes of the crystal lattice; and the relation of the axial angles of the direct lattice α , β , γ , to the axial angles of the reciprocal lattice, α^* , β^* , γ^* .

modifications. The formulas are expressed in terms of $(\text{SiO}_4)_2$, which represents one-fourth of the cell content of rosenbuschite. Constituents amounting to less than one-tenth of an atom in the cell containing $(\text{SiO}_4)_8$ are neglected.

Table 4.
Wöhlerite Family.

Wöhlerite group	
Rosenbuschite	$(\text{Na}, \text{Ca}, \text{Mn})_3 (\text{Fe}''', \text{Ti}, \text{Zr}) (\text{SiO}_4)_2 \text{F}$
Wöhlerite	$(\text{Na}, \text{Ca})_3 (\text{Mn}, \text{Fe}'', \text{Fe}', \text{Ti}, \text{Cb}, \text{Zr}) (\text{SiO}_4)_2 (\text{F}, \text{OH})$
Hiortdahlite	$(\text{Na}, \text{Ca})_3 (\text{Mn}, \text{Fe}'', \text{Ti}, \text{Zr}) (\text{SiO}_4)_2 (\text{F}, \text{OH})$
Guarinite	$(\text{Na}, \text{Ca})_3 (\text{Mg}, \text{Mn}, \text{Fe}'', \text{Cb}, \text{Zr}) (\text{SiO}_4)_2 (\text{O}, \text{F}, \text{OH})$
Johnstrupite	$(\text{Na}, \text{Ca})_3 (\text{Mg}, \text{Fe}'', \text{Al}, \text{Y}, \text{Ce}''', \text{Ti}, \text{Zr}) (\text{SiO}_4)_2 (\text{F}, \text{OH})_2$
Additional members	
Låvenite	$(\text{Na}, \text{Ca})_2 (\text{Mn}, \text{Fe}'', \text{Fe}''', \text{Ta}, \text{Cb}) (\text{Ti}, \text{Zr}) (\text{SiO}_4)_2 (\text{F}, \text{OH})$ and others.

Berman reluctantly retains rosenbuschite in the wollastonite group, in view of the crystallographic analogy previously indicated by the present writer. Since this analogy has proved to be partly fallacious, it seems proper to transfer rosenbuschite to the Wöhlerite Group, with which it has evident chemical affinities, even though there is as yet no apparent crystallographic similarity between the structural lattice of rosenbuschite and the morphological lattices of the members of the Wöhlerite Group, within which there are evident morphological analogies. As formulated above, the constitutions of rosenbuschite, wöhlerite, hiortdahlite and guarinite are closely similar, the ratio Na:Ca being nearly 1:2 in each case. A general formula for the four species is:



in which X is Mg, Mn, Fe'' , Fe''' , Cb, Ti, and slight mutual substitutions are tolerated.

Johnstrupite is slightly removed from the first four species in the above arrangement since the analysis indicates twice the typical proportion of (F, OH). Låvenite is still farther removed as

shown by the replacement of one-third of the (Na, Ca) bracket by other cations.

In spite of its marked chemical relation to the Wöhlerite Group rosenbuschite is placed in this group only tentatively. An X-ray study of the minerals of the Wöhlerite Group will be necessary to show whether the chemical analogy with rosenbuschite is supported by structural similarities.

Summary.

A study of rosenbuschite from Langesundsfjord, Norway, leads to a characterization that differs essentially from the original description of Brøgger (1890). Rosenbuschite is triclinic; $a_0=10.12 \text{ \AA}$, $b_0=11.39 \text{ \AA}$, $c_0=7.27 \text{ \AA}$; $a_0:b_0:c_0=0.8887:1:0.6383$; $\alpha=91^\circ 21'$, $\beta=99^\circ 38\frac{1}{2}'$, $\gamma=111^\circ 54\frac{1}{2}'$. Forms: $a\{100\}$ (cleavage), $b\{010\}$, $n\{120\}$. $V_0=763.2$ cubic $\text{\AA}$; $d=3.315$ (Cleve, 1890); $M=1533$. Cell content: $(\text{Na}, \text{Ca}, \text{Mn})_{12}(\text{Fe}''', \text{Ti}, \text{Zr})_4\text{Si}_8\text{O}_{82}\text{F}_4$.

Colour, palest orange-gray; pleochroism negligible. $X=c[001]$; Z inclined to the normal to the cleavage $\{100\}$ at $28\frac{1}{2}^\circ$ nearly in the acute angle γ . Indices (Na): $nX=1.678$, $nY=1.687$, $nZ=1.705$, all ± 0.002 . Positive; $2V=78^\circ$; $r > v$ weak.

Except for the equality of the identity periods in the direction of morphological elongation in rosenbuschite and wollastonite, there is no structural or chemical similarity between the two minerals or between rosenbuschite and pectolite. The compositions of rosenbuschite, wöhlerite, hiortdahlite and guarinite may be expressed by the general formula: $(\text{Na}, \text{Ca})_{12}(\text{X}, \text{Zr})_4(\text{SiO}_4)_8(\text{F}, \text{OH})_4$ in which X is Mg, Mn, Fe'' , Fe''' , Cb, Ti; this suggests a relationship which requires to be tested by an X-ray study of the Wöhlerite Group.

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VOLCANIC ASH FROM VATNAJØKULL

(A MODERN FÖRMATION OF SIDEROMELAN)

BY

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I.

The vast glacier Vatnajökull in southeastern Iceland is known as an area of intense volcanism. Throughout historical time it has been in vigorous, incessant activity. For the last hundred years or so periodic outbursts seem to have occurred at fairly regular intervals, 5 to 12 years according to Thorkelsson (7). Most of them have been violent, explosive eruptions accompanied by tremendous glacier-bursts, the so-called jökulhlaup.

The last two greater outbursts took place in 1922 and 1934. Both were explosive and accompanied by jökulhlaup and ejection of ash and pumice. No extrusion of lava was observed, but very likely any possible lava flow would have been concealed by the glacier.

Descriptions of the materials erupted are now available; but petrographically the records are very incomplete, some even misleading. The petrographic character of the volcanic ash from the last two eruptions seems therefore worthy of discussion.

II.

Some uncertainty has prevailed as to the exact location of the craters in the frozen wastes of Vatnajökull. Sapper (6) places special emphasis on two loci of activity: Grimsvøtn and Oræfajökull at $64^{\circ} 12' N$, $17^{\circ} 25' W$ and $64^{\circ} 02' N$, $16^{\circ} 39' W$ respectively. However, the location of Grimsvøtn as given by Sapper corresponds to that of the glacier-lake Grænalón on the modern maps of Iceland. The region around this lake was explored by Muir and Wigner (10) in 1904 who contended that no Recent volcanic activity had ever taken place there. Later observations by Áskelsson (1) corroborates this. But about 25 km North of Grænalón in the very central parts of the glacier Wadell (8) in 1919 encountered Recent craters, at that

time, of course, partly buried by the ice. He called the place "Svíagígur". It is probable that most of the eruptions listed in Sapper's book as having occurred at "Grimsvøtn" actually took place at Svíagígur. In 1935 Áskelsson was able to identify the scene of eruption of 1934 with Svíagígur. But at the same time he re-named the place and called it "Grimsvøtn" (later officially confirmed). But as distinct from the old Grimsvøtn the location of this new Grimsvøtn (= Svíagígur) is $64^{\circ} 23.6' \text{ N}$, $17^{\circ} 21.5' \text{ W}$. Undoubtedly this is the centre of the eruptions of 1922 and 1934, and probably the centre of many of the older eruptions.

III.

Dr. Th. Thorkelsson, director of the Meteorological Institute ("Veðurstofan") in Reykjavik, kindly gave me for petrographical examination a number of ash samples collected at various places in Iceland during the ash-falls of 1922 and of 1934.

First we shall consider the ash of 1922: The eruption and the ash-fall have been carefully described by Thorkelsson (7). The days of heaviest ash-fall were the 5th, 6th, and 7th of October. South and southwesterly winds prevailed, the ash thus being carried over large areas of Northern and Eastern Iceland. Thorkelsson examined the ash from various localities, measured the areas covered and the thickness of the ash layers, and concluded that during these three days a minimum amount of 15 million tons ash had fallen down on Iceland, not to speak of what had fallen into the sea. From this fall I received three samples:

- (1) Oct. 5, 1922; a violent outburst producing minimum $1\frac{1}{2}$ million tons ash. Sample collected at Eskifjord, 180 km ENE of the crater.
- (2) Oct. 6, 1922; another violent outburst producing minimum 11 million tons ash. Sample collected at Papey, 150 km E of the crater.
- (3) Oct. 7, 1922; violent outburst producing minimum $2\frac{1}{4}$ million tons ash. Sample collected at Grimstad, 150 km NNE of the crater.

The eruption of 1934 commenced on March 30. It was very violent in the beginning. Nielsen (3) estimated that about 10 km^3 of ice was melted. During the following month the activity gradually died off. The column of ash thrown out of the vent was measured

to be between 10 and 12 km high. The ash-fall has been described in some detail by Áskelsson (1), but no estimate of the total amount of ash erupted has been made.

The site of eruption was later visited by several expeditions. Scoriae, pumice, and ash were observed and examined by Áskelsson (1), Nielsen (3) and Noe-Nygaard (4). From this eruption I have examined ash samples collected at Papey, Grimstad, Reykjahlid, Fagerhólsmyr, Vapnafjord, and Hólar.

IV.

Ash from the eruption of 1922, collected at Papey, Eskifjord, and Grimstad is essentially a homogeneous, brownish, transparent glass whose index of refraction is

$$n = 1.610—.$$

About 1% of crystalline material is present: Mostly feldspar (plagioclase of composition 85% anorthite, mean index of refraction being $\beta = 1.575$), but in the sample from Grimstad also odd grains of olivine were observed ($+2V - 85^\circ$, consequently a Mg-rich olivine).

Ash from the eruption of 1934 seems to be the same in all localities. It is also identical with the ash that fell in 1922. To give an indication of the constancy of the composition of the ash the following individual data are given:

Grimstad: Glass: $n = 1.610$, mostly brownish, but some grains are opaque. 2—3% plagioclase, $\beta = 1.575$ (85 An). Odd grains of olivine.

Papey: Glass: $n = 1.610$, brownish, homogeneous. 1% plagioclase, $\beta = 1.575$ (85 An). Very little olivine.

Reykjahlid: Glass: $n = 1.610$, mostly brownish, but many opaque grains are met with. 2% plagioclase, $\beta = 1.575$ (85 An). Some small hair-shaped crystals only $\frac{1}{100}$ mm long occur in some glass grains. Trace of olivine.

Fagerhólsmyr: $n = 1.610$. 1% plagioclase, $\beta = 1.575—1.570$ (85—80 An). Olivine not observed.

Vapnafjord: Glass: $n = 1.610$, some grains are opaque. 1% plagioclase, $\beta = 1.575$ (85 An). Odd grains of olivine.

Hólar: Glass: $n = 1.610$. 1% plagioclase, $\beta = 1.575$ (85 An). Olivine not observed with certainty.

Table 1.

Chemical Analyses of Volcanic Ash from Vatnajökull.

	I	II	III	IV
SiO ₂	49.80	49.73	48.40	47.40
TiO ₂	2.83	2.51	3.20	3.10
Al ₂ O ₃	13.87	14.80	14.00	14.50
Fe ₂ O ₃	1.84	3.10	2.30	3.00
FeO.....	12.38	11.53	12.80	11.35
MnO.....	0.16	0.15	-	-
MgO.....	4.92	4.92	4.70	5.00
CaO.....	9.75	9.55	10.00	10.50
Na ₂ O.....	3.17	2.86	2.50	3.10
K ₂ O.....	0.55	0.52	0.23	0.36
P ₂ O ₅	0.22	0.23	0.20	0.18
H ₂ O+.....	0.44	0.40	-	-
H ₂ O-.....	0.07	0.08	-	-
Cr ₂ O ₃	nil	n.d.	-	-
SO ₃	nil	n.d.	1.00	0.95
Total.....	100.01	100.28	99.43	99.54
Cl.....	0.02			

- I. Ash collected at Papey, Oct. 6, 1922; Barth analyst.
 II. Ash collected at Papey, April 2, 1934; Barth analyst.
 III. Ash collected at Meðalland, 1934; quoted from Áskelsson, op. cit. p. 39, analyst anonymous.
 IV. Ash collected on glacier, 10 km West of outburst, 1934; quoted from Áskelsson, op. cit. p. 39, analyst anonymous.

Table 2.

Norms of Volcanic Ash.

	I	II	III	IV
Q.....	-	1.4	2.2	-
or.....	3.3	3.3	1.3	2.2
ab.....	26.7	24.1	21.1	26.2
an.....	22.0	25.9	26.1	24.5
wo.....	10.4	8.4	9.2	10.9
en.....	11.2	12.2	11.7	8.9
fs.....	15.5	14.9	16.4	9.4
ol.....	1.7	-	-	5.4
mt.....	2.8	4.4	3.2	4.4
il.....	5.3	4.7	6.1	5.9
ap.....	0.5	0.5	0.5	0.4

Number of analyses as in Tab. 1.

Table 3.
Niggli Parameters of Volcanic Ash.

	I	II	III	IV
si	122	120	117	111
al	20	21	20	20
fm	47	47	47	45
c	25	25	25	27
alk	8	8	6	8

Number of analyses as in Tab. 1.

Chemical analyses were made of ash collected at Papey, Oct. 6, 1922, and at Papey, April 2, 1934. With these two new analyses are compared two analyses of the ash of 1934 published by Áskelsson.

In ash from Eskifjord (1922) ferrous oxide was determined as follows:

$$\text{FeO} = 11.95\%.$$

Tab. 2 and 3 give account of the theoretical, normative mineral composition, and the Niggli parameters, of the various ash samples.

The norm shows that the ash is just saturated with respect to silica. The normative feldspar is andesine-labradorite; the modal plagioclase, basic bytownite, reflects the invariably more calcic character of the early-formed plagioclase. Again, magnesia-rich olivine, observed in samples with very little or no normative olivine, reflects the well-known reaction relation between olivine and pyroxene.

The microscope studies and the analyses thus prove the identity of the materials erupted in 1922 and in 1934. It is furthermore clear that the ash is not phreatic but, in spite of the explosiveness of the eruptions, truly magmatic, viz: glass produced by rapid chilling of a lava of basaltic composition.

About one year ago I (2) was able to establish the position of the boundary surface that separates basaltic liquids precipitating feldspar from those liquids that precipitate pyroxene ($\pm$ olivine). The position of this boundary surface was given by the following equation:

$$ab' + 2di' + 2.3hy' = 123.$$

If the left side of the equation, which for short may be called f (norm), equals 123 (approximately) the basalt lies on the boundary surface. If it is smaller or greater than 123 the basalt lies in the plagioclase field or in the pyroxene field respectively.

For the two new analyses we obtain:

Papey 1922, f (norm) = 123

Papey 1934, f (norm) = 118.

A simultaneous precipitation of plagioclase and pyroxene would have taken place, therefore, in this glass, if allowed to have cooled slowly. That this deduction is correct is also indicated by the products of the incipient crystallization: plagioclase and olivine. Characteristic features of this glass are thus: basaltic composition on the boundary surface plagioclase $\rightleftharpoons$ pyroxene, and complete saturation with respect to silica. It has therefore all the earmarks of a plateau basalt lava.

It is a well-known fact that volcanoes extruding basaltic lavas differ from those producing acid lavas in the character of their eruptions. The basic volcanoes do not exhibit the more violent phases of volcanism, and are not likely to explode or throw great quantities of magmatic ash up in the air. Vatnajökull is a conspicuous exception to this rule; it is also the only known sub-glacial basic volcano. It is reasonable, therefore, that its explosiveness is caused by the superincumbent load of ice which it has to break through to find egress for its incarcerated lavas and gases.

V.

The production of volcanic glass in Vatnajökull is an example of modern sideromelan in its making; the glass agrees very closely with the substance for which Peacock (5) has revived the old term "sideromelan". Excerpt: "Sideromelan is a black, lustrous, mostly anhydrous basaltic glass which is pale coloured and translucent in thin section; it is known only in fragmental volcanic ejecta. In Iceland sideromelan is the product of drastically chilled, sub-glacially extruded basalt magma. This mode of formation results in the invariable fragmentation of the material and the inhibition of ore-separation producing the characteristic translucency" (op. cit. p. 74).

Peacock points out that sideromelan does not, of course, conform with the criteria of a mineral species, as von Waltershausen (9) thought. The composition of basalt magma varies somewhat and, accordingly, the composition of sideromelan must vary; but all the inter-Glacial sideromelans in Iceland examined by Peacock seem to have a fairly constant composition: olivine and plagioclase persistently appearing as the only crystallized products and the refractive index varying only between the narrow limits of 1.604 to 1.615. Thus the composition must also be similar to that of the Recent sideromelan produced by the eruptions of Vatnajökull.

In the Pleistocene "Palagonitformation" sideromelan-tuff and breccia are abundant; and, furthermore, Peacock has proved that palagonit itself is the hydrogel of sideromelan. The palagonite-tuffs thus being the older sideromelan-tuffs which have suffered hydration usually by submersion or by hot-spring action. It seems very probable, therefore, that the great preponderance of palagonite in the Pleistocene formations of Iceland is due to the fact that favourable conditions for the formation of sideromelan were present: ultra-rapid chilling effect of the Pleistocene ice-sheet on the products of sub-glacial volcanoes.

This contention of Peacock is now verified by the observation that modern sideromelan is produced by the chilling effect of the Vatnajökull ice-sheet on basalt lava of sub-glacial outbursts.

The chief object of the two latest Danish-Icelandic expeditions to Vatnajökull was to observe at close quarters modern analogues of processes and events instrumental in the shaping of the inter-Glacial "Palagonitformation". Hope was entertained that some of the new-formed products at Vatnajökull might correspond to the tuffs or breccias in the "Palagonitformation" and thus give a clue to the genesis of various rock types of alleged sub-glacial origin.

In their recent report Nielsen and Noe-Nygaard (3) express their disappointment of not having encountered any such products. But I think it is safe to say that in the production of the volcanic ash we do have a modern analogue to the formation of the inter-Glacial sideromelan-tuff, the mother substance of an essential unit of the "Palagonitformation".

Summary.

Volcanic ash erupted from a sub-glacial volcano in Vatnajökull, 1922 and 1934, proved to be a brownish, transparent glass of plateau basaltic composition. It is a sideromelan (as defined by Peacock), representing thus a modern analogue to the Pleistocene sideromelans which in Iceland are the products of sub-glacially extruded basalt magma drastically chilled by contact with the superjacent Pleistocene ice-sheet.

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NOTIZ ÜBER DIE FÄRÖERKOHLE

VON

GUNNAR HORN

Die Färöer (Föroyar) sind bekanntlich aus tertiären Basalten aufgebaut, und auf Suduröy, der südlichsten Insel der Inselgruppe, gibt es zwischen den Basaltströmen einen Horizont mit Kohle und Tonlager (seit alter Zeit bekannt), wo jetzt regulärer Bergwerksbetrieb aufgenommen wird¹. Diese Notiz soll nur einige Bemerkungen über die Kohle enthalten, die nicht so geringes Interesse bietet.

Bei Rossarók westlich von Trangisváð auf Suduröy haben wir folgendes Profil:

	m
Basalt	
Schieferton	10
Kohlenflöz	1,3
Ton (Liegende)	0,3
Basalt	

Das Profil zeigt, daß wir während der Zeit zwischen den beiden Basaltergüssen eine längere ruhige Periode mit Ablagerung von Ton, eines Kohlenflözes und wieder Ton gehabt haben, bis dann alles von einem neuen Basaltstrom bedeckt wurde. Auf den Färöern wurden auch Pflanzenfossilien gefunden, aber die einzige Art, die mit Sicherheit bestimmt werden konnte, war *Sequoia Langsdorfii* Brongn. sp. (Hartz 1903). Nach den generellen geologischen Verhältnissen muß das Alter des Flözes immerhin wohl dem älteren Teil des Tertiärs zugerechnet werden (vgl. Callisen 1933 mit ausführlichem Literaturverzeichnis).

¹ Seit langem haben jedoch Bauern auf Suduröy ständig einige Kohlen für eigenen Gebrauch gewonnen. Ganz unbedeutende Kohlenvorkommen aus anderen Niveaus sind auch bekannt.

Seit langem unterscheidet man auf den Färöern „Glanzkohle“ und „Mattkohle“. Die Glanzkohle ist natürlich *Vitrit* und die Mattkohle *Durit*, aber auch Kohlenschiefer. Ein Profil des Kohlenflözes in der Rangabotn Grube bei Trangisvág zeigt folgendes:

Schieferton	m
Glanzkohle und etwas Mattkohle	0,65
Tonschicht	0,04
Mattkohle und Kohlenschiefer	0,15
Tonschicht	0,08
Mattkohle, teilweise mit Glanzkohle	0,40
Heller Ton (Liegende)	

Eine Analyse von Glanzkohle und Mattkohle, ausgeführt von Herrn Dr. Aufhäuser und von Herrn Gernow, dem Direktor der A S Færø-Kul, freundlichst zur Verfügung gestellt, ergab folgendes Resultat:

	Glanzkohle	Mattkohle
Feuchtigkeit	14,50	14,25
Asche	4,98	20,05
Koks (nicht backend)	53,15	57,33
Flüchtige Bestandteile	32,35	28,42
Schwefel	0,42	1,04
Oberer Heizwert	5981 Kal	4798 Kal
Unterer Heizwert	5676 »	4518 »
<i>Zusammensetzung der Reinkohle:</i>		
Fixer Kohlenstoff	59,82	56,74
Flüchtige Bestandteile	40,18	43,26
Kohlenstoff	76,14	76,28
Wasserstoff	5,03	5,58
Sauerstoff, einschl. Stickstoff	18,83	18,14

Der Strich der Kohle ist schwarzbraun und durch Behandlung mit KOH erhält man eine dunkelbraune Lösung. Bei Behandlung mit 10 Proz. HNO_3 ergibt die Glanzkohle eine farblose (schwach gelbliche) Lösung, und die Mattkohle gibt der Flüssigkeit eine grünlichgelbe bis hellgelbe Farbe. Nach diesen Reaktionen ist es deutlich, daß die Kohle zur Kategorie Braunkohle gerechnet werden muß. Wollte man aber nach dem Aussehen der Kohle urteilen, würde man sie eher zur Kategorie Steinkohle rechnen, da es *typische schwarze Streifen-*

kohle ist. Die einzelnen Streifen von Vitrit können einige Zoll dick vorkommen und haben oft Linsenform. Die dickeren Vitritschichten haben nicht den Charakter von Bändern, sondern sind unregelmäßiger und stellen zweifellos Stücke von größeren Baumstämmen dar. Es wurden auch Vitritstücke in Form von kleineren flachgedrückten Stämmen (sogar mit Teilen von Ästen) vorgefunden. Der Vitrit ist hochglänzend und spröde und hat einen ausgeprägten Pechglanz. Charakteristisch für den Vitrit in der Färöerkohle ist, daß man darin in den meisten Fällen schon makroskopisch die Holzstruktur erkennen kann und der ganze Vitrit in dieser Kohle scheint aus Holz entstanden zu sein. Die „Mattkohle“ entspricht also dem Durit, der einerseits viel Einlagerungen von Vitrit enthalten kann und andererseits so viel an anorganischen Bestandteilen, daß er ein Kohlenschiefer wird. *Fusit* (Holzkohle) kommt auch vor.

Die Färöerkohle ist also eine alttertiäre Streifenkohle, die sich hinsichtlich des Inkohlungsgrades an der Grenze von Braunkohle und Steinkohle befindet. Sie gehört zu der Kategorie von Kohlen, die bei dem immer umfassender werdenden Wissen von den Kohlenlagern der Welt größer und größer wird, wo man sich weder für Braunkohle noch für Steinkohle entscheiden kann. Nach den vorerwähnten Reaktionen gehört die Kohle zur Braunkohle, ihr Aussehen (und teilweise die Analyse) verweist sie aber auch zur Steinkohle. Will man sich an die bisher üblichen Bezeichnungen halten, so ist die Färöerkohle als Glanz(braun)kohle (Gothan etc. 1927) zu bezeichnen und zählt demnach zu der Klasse der bekannten „Peissenberger Pechkohle“.

Wie hat sich nun diese Kohle gebildet? Wegen der dicken Tonschicht über der Kohle ist eine Erwärmung durch direkte Kontaktwirkung des über die Tonschicht hinaus sich ergießenden Basalts ausgeschlossen, wie auch der Druck hierbei wenig über Atmosphärendruck gewesen ist. Nach Helland (1880) soll die Mächtigkeit der über dem Kohlenhorizont liegenden Basaltmassen ganze 3000 Meter betragen. Hier ist zu bemerken, daß das Kohlenflöz auf Suduröy ein Einfallen von etwa 4° gegen NO hat, und kommt man gegen Norden, gelangt man zu immer höheren Basaltbänken. Von einer Faltung kann hier kaum die Rede sein, eher von einer durch Erdbewegungen verursachten Schrägstellung. Wir müssen daher glauben, daß das ursprüngliche Tonlager einst unter einem Belastungsdruck von 3000 m oder mehr Basalt gewesen ist, einem Druck von etwa 900 Atm. entsprechend. Bei einer normalen Temperatursteigerung

sollte man in einer Tiefe von 3000 m eine Temperatur von etwa 100° C haben. In dem damaligen Vulkangebiet ist aber wohl die Temperatursteigerung schneller vor sich gegangen, so daß wir unschwer in den Bereich der Grenztemperatur von 325° gelangen würden, die für die Umwandlung von Braunkohle in Steinkohle nach Erdmann (1924) und später experimentell bestätigt von Gropp und Bode (1932) als notwendig angesehen wird.

Die Entwicklung der tertiären Färöerkohle als *Übergangskohle* zwischen Braun- und Steinkohle läßt sich demnach darauf zurückführen, daß sie einer Metamorphose (Druckdestillation) unterworfen gewesen ist, wobei das Gewicht der darüber lagernden Basaltmassen (vielleicht etwa 3000 m) den Druck gegeben hat und die notwendige Temperatur von ungefähr oder annähernd 300° ist durch die Temperatursteigerung nach dem Innern der Erde entstanden. Die geothermische Tiefenstufe betrug dann ungefähr nur 10 m, gegenüber ca. 30 m im allgemeinen, was in einem vulkanischen Gebiet, wie es die Färöer damals waren, sehr wohl möglich ist, wenn also nicht die Basaltmassen noch mächtiger gewesen sind.

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CALLISPHENUS GRACILIS, N. GEN., N. SP. A FOSSIL ALGA FROM THE WENLOCK OF THE OSLO REGION

BY
OVE ARBO HØEG

WITH 2 PLATES

The specimen described below was found in August, 1910, on the small island of Kommersøy near Holmestrand, in the Oslo Fjord, by Miss Mary S. Johnston, and presented to the British Museum (Natural History) in 1936. Mr W. N. Edwards found that it was probably a new species, not previously described, and sent it to me, asking if it was already known in Norway, and suggesting that it might be an impression of one of the *Dasycladaceae*. The fossil is certainly not known before from the Paleozoic formations of Norway, and upon the whole it appears to represent a new and very interesting type.

I beg to express my respectful thanks to the Trustees of the British Museum and to Mr Edwards personally for kind permission to describe the fossil here.

The locality is situated on the East side of the island of Kommersøy, about equally distant from its North and South point. As far as Miss Johnston's memory serves her it should be somewhere about the middle of the profile published by J. Kiær in "Das Obersilur" (1908, fig. 48, p. 216, compare Map IV), in a black shale a little above water level: if so, it should belong to the 8 b, the Zone with *Chonetes* sp. The details cannot be given with full certainty, on account of the long space of time elapsed since the collection.

The specimen is a small piece, about 9×6 cm, of a dark, calcareous rock, weathering yellowish grey, with two fossils on it; the counterpart is also preserved.

The fossil is wedge-shaped, the larger specimen 22 mm long and 5 mm broad, the other one very slightly smaller. The greatest breadth is near the top, and from here the thallus is slowly tapering towards the base, with straight sides, whereas the top is rounded. The very base itself is not preserved; at least in one case there

are two very delicate lines, forming an irregular continuation of either side of the thallus, but their nature and significance could not be made out.

There is not the slightest trace of calcification, the fossil consisting of an impression with a thin black layer of carbonaceous matter. The surface is somewhat uneven, and by means of various kinds of illumination, and partly by immersion in alcohol, some structural details can be made out.

There is a longitudinal central cell, visible only in some places in the upper half of the thallus; it stops a little below the top itself (Pl. 1, figs 2—3). Mostly it is quite narrow, merely in the shape of a dark line; but in places, especially near the top, it is widened to a breadth of 0,3—0,5 mm. The rest of the thallus consists of a dense tissue, which in the central parts is seen as a reticulation, whereas towards the sides it has the form of lines curving out towards the surface and reaching it at a right angle. When examined moistened with alcohol and under a sufficiently strong magnification, the cells have the appearance of being tubes, 0,1—0,13 mm in diameter, often regularly hexangular in cross-section, and separated by cell walls, which are often very thin, but in many cases thickened in the corners. There is no trace of verticillation. The original nature of the superficial tissues cannot be made out. There may have been a kind of cortical layer, which has now more or less completely disappeared. In a few places there are seen cell walls extending from the main body of the fossil, e. g. in one place on the right hand side of Pl. 2 fig. 2, and at the top of the same specimen, as shown on Pl. 2 fig. 3. In the latter case they look like small tufts of hair; it is difficult to decide whether they represent cell walls of a cortical tissue, destroyed during the process of fossilization, or remains of a cover of hairs present in the living organism.

As to the nature of this fossil, it could scarcely be doubted that it is an alga. Its affinity to the *Dasycladaceae* suggests itself at first sight, on account of what seems to be an axial tube, with lateral cells radiating out from it. — Certainly, objections may be raised to this view: First, because it is not definitely proved that the central organ really does correspond to the axial cell of a *Dasycladaceae*; but, on the other hand, at least personally I cannot see any objection to this interpretation of it, and strong positive evidence is afforded by its structure in the upper part of one of the specimens, as

seen in Pl. 1 figs. 2—3. The fact that it is thinner than in most previously known algae of the said group is no hindrance. More serious would be another objection, *viz.* to regarding the other cells as lateral tubes, analogous to those of, for instance, a *Dasycladus*; in our fossil they really seem to form a coherent tissue (Pl. 1 fig. 4), rather different from the ordinary discrete lateral appendages. In so far, there is rather some resemblance to algae of quite different groups, both brown and red. But if they are really tubes without any cross-walls (and that is what they look like), the mere fact that they cohere does not seem to be a feature of such importance as to make the affinity to the *Dasycladaceae* unacceptable; it is a kind of structure which may, to some extent, be connected with the complete lack of incrustation with lime. Definite proofs *pro* or *contra* could scarcely be produced; but at least provisionally it seems to be justifiable to regard our alga as a member of the *Dasycladaceae* or a related group. It has, however, a very isolated position.

All other fossil algae of the Paleozoic formations of Norway are very different from this new form. Those which are regarded, with more or less certainty, as members of the *Dasycladaceae*, *viz.* *Dasyporella*, *Vermiporella*, etc., are completely calcified and of quite another anatomical structure. The only uncalcified algae previously discovered in this region, *Chaetocladus capillatus* from the Ludlow of Ringerike, is not preserved in such a way that its anatomy could be studied, and even if it should belong to the *Dasycladaceae*, an idea which has been suggested but which is far from proved, it has certainly a very remote affinity to the one in question.

Similar is the case with the other fossil algae with which it might be compared. It is, then, necessary to institute a new genus for it. I propose to call it *Callisphenus*; it is characterized by its lack of calcification and by its slender axial cell, giving off, without any verticillation, numerous tubular lateral cells which radiate towards the surface, forming a coherent tissue. Organs of reproduction unknown. At least in the present species, *C. gracilis*, n. sp., the thallus is claviform and slender. The type specimen, from the Wenlock on the island of Kommersøy, near Holmestrand, coll. Miss Mary S. Johnston, is preserved in the British Museum (V. 24775). A paratype (counterpart) in the Paleontological Museum of the University, Oslo (PA 1321).

Plate 1.

Callisphenus gracilis, n. gen., n. sp.

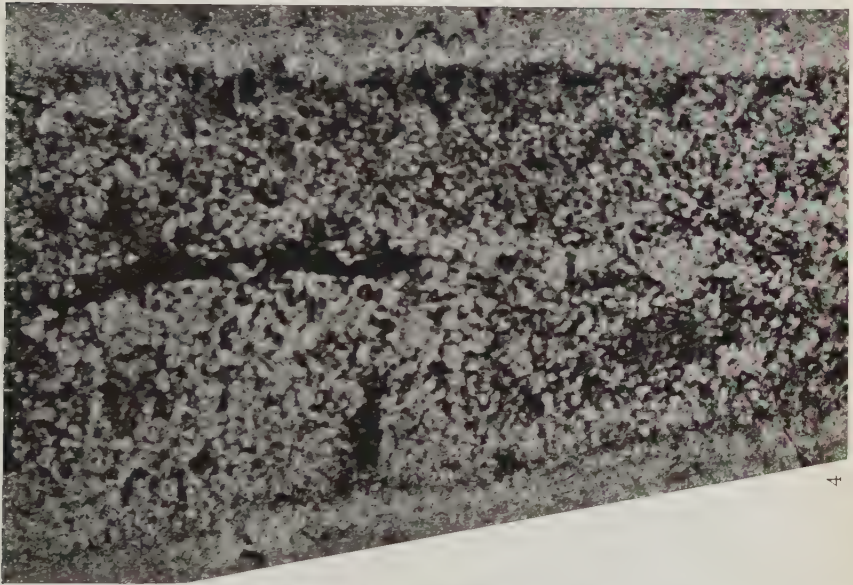
Holotype, from the Silurian of Kommersøy, Oslo region, coll. Miss Mary S. Johnston, 1910. (Brit. Mus. V. 24775.) From photographs without retouch.

Fig. 1. Photographed dry. — Nat. size.

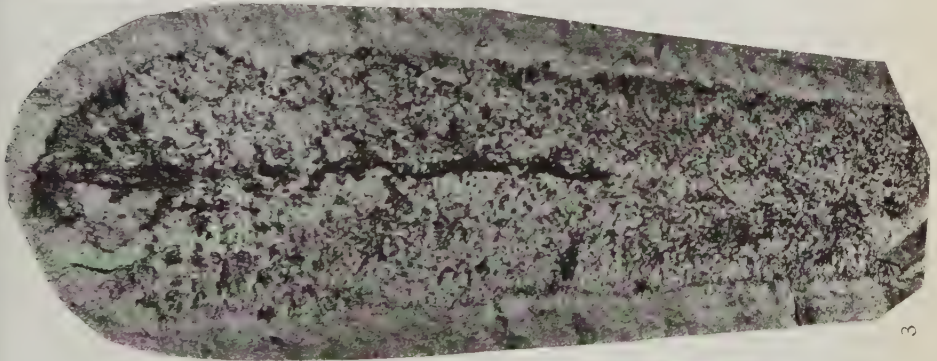
„ 2. The right hand specimen of fig. 1. Upper part, photographed dry, showing the relief of the central cell. — $\times 8$.

„ 3. Same, photographed in alcohol. -- $\times 8$.

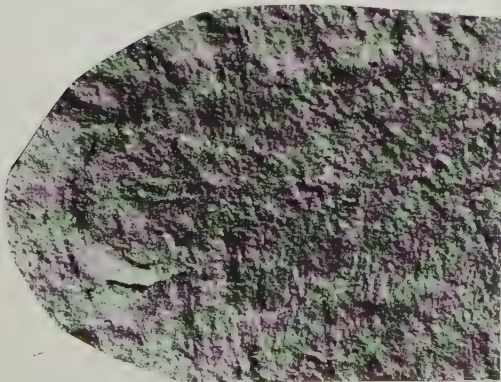
„ 4. Part of fig. 3. — $\times 16$.



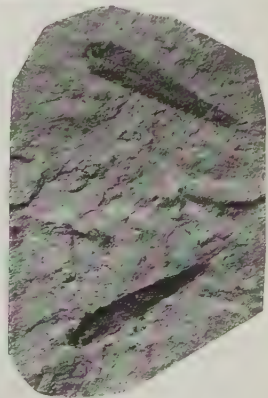
4



3



2



1

Plate 2.

Callisphenus gracilis, n. gen., n. sp.

Holotype, as Pl. 1.

- Fig. 1. Same specimen as Pl. 1 figs 2—4, photographed dry. — $\times 4$.
„ 2. The left specimen of Pl. 1 fig. 1, photographed dry. — $\times 4$.
„ 3. Same specimen, photographed in alcohol. — $\times 8$.
„ 4. Part of same specimen, photographed dry. — $\times 8$.



SCHETELIGITE, A NEW MINERAL

PRELIMINARY NOTE

BY

HARALD BJØRLYKKE

In the present paper a short description is given of a new granite pegmatite mineral which I have named after my late chief and teacher Professor Jacob Schetelig, director of the Mineralogical Museum in Oslo, unquestionable the best judge of Norwegian pegmatite minerals in his time.

The last find of a new Norwegian mineral (1910) was Schetelig's detection of thortveitite, a silicate of scandium.

The mineral scheteligite was found in the summer of 1933 in a small pegmatite dike at Torvelona about 200 m east of the farm Øvre Ljosland in Iveland. That summer only one crystal of the mineral was found, and X ray spectrograms showed it to be a hitherto undescribed mineral. Not until the summer 1936 sufficient material for a chemical analysis could be collected. In all 20—30 rock samples containing small crystals of the mineral were found. The largest crystal had a weight of a little more than 0.5 gr.

Description. The powdered mineral is pale yellow to greyish, under the microscope translucent in reddish-brown colors. Large pieces are brilliantly black with perfect conchoidal fracture; cleavage none, isotrope, hardness 5.5, sp. gr. 4.74.

It usually occurred imbedded in quartz, more seldom in feldspar. The crystals exhibit an orthorhombic habit, with pyramide faces developed on only one side while the other parts of the crystals were without crystal outlines. Owing to the roughness of the crystal faces and the fact that only two faces were present in any one zone it has not been possible from the material available to determine the exact crystal symmetry of the mineral. Nor did X ray powder diagram of the heated mineral give any result.

Chemical analysis. An amount of 0.9 gr. of mineral substance was picked out for chemical analysis, and a series of X ray spectrograms was carried out to make sure that the material was homogeneous.

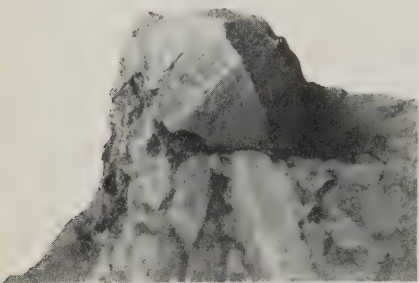


Fig. 1. Scheteligite in quartz.
Torvelona, Iveland. 5x.

The mineral contained, however, always small inclusions of microcline and quartz which were hard to get rid of. Particularly microcline stuck tenaciously to the powder, thus constituting the chief contamination in the sample prepared for chemical analysis. The amount of SiO_2 found in the analysis was therefore calculated as microcline.

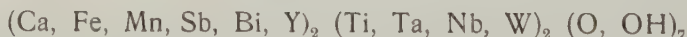
The chemical analysis was carried out at the Mineralogical Institute of the University by Mr. B. Bruun, M. A. with

kind permission and helpfulness of the director, Professor Dr. Tom. Barth. Owing to the unusual combination of elements, the chemical analysis was very difficult. The X ray spectral analyses were made by me.

The mineral powder was insoluble in strong acids but was brought into solution by digestion with H F. Sb and Bi were precipitated as sulphides, and Ti, Nb, Ta, and W were precipitated together as oxydes. Of the oxydes TiO_2 was colorimetrically determined, while no chemical separation of the other oxydes was effected. The relative content of these oxydes was determined from intensity data of their lines in an X ray spectrogram. For the other elements the usual chemical methods were used.

All chemical precipitates were tested on purity by X ray spectroscopy analyses and in a few cases of incomplete separation the chemical procedure was repeated. Analytical errors of any consequence were in this way eliminated.

According to the analysis (table 1) scheteligite has the formula:



Since the composition of scheteligite differs very much from any previously described mineral the present data are not sufficiently complete for a full discussion of the systematic relations of the mineral. I hope, however, to be able to take up this problem in a later paper.

Occurrence and paragenesis. The pegmatite dike in which the scheteligite was found is exposed in a road-cut and forms a small lense-shaped body imbedded in amphibolite. Much of it had been quarried as road-metal. Later the pegmatite was mined in search for scheteligite so today but little is left of it. The pegmatite differs from the ordinary granite pegmatites in Iveland by being composed chiefly

of plagioclase feldspar with only subordinate amounts of microcline. It is relatively rich in tourmaline, and constitutes the only known occurrence of native bismuth in Iveland. The complete mineral paragenesis is: Alvitte, euxenite, monazite, scheteligite, biotite, muscovite, ilmenite, magnetite, bismuthinite, native bismuth, thortveitite, beryl, spessartite, tourmaline, microcline, plagioclase, and quartz.

Many of the rare minerals of this pegmatite exhibit a peculiar thin prismatic habit: Euxenite in needle-shaped or in thin

blade-like crystals; alvitte and monazite in long prismatic crystals. Thortveitite is interesting; it is present in small well developed crystals frequently less than 1 mm across. It occurs imbedded in spessartite, beryl, and magnetite. The color is greenish, grey, yellow to white. Small crystals of beryl occur abundantly. A more complete description of scheteligite and the mineral paragenesis of the dike will be given later.

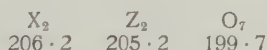
I want to express my best thanks to the Fridtjof Nansen Fund for grants given to me for investigation of the Iveland pegmatites. I am also greatly indebted to Olav Landsverk Iveland who has helped me with the field work and to Miss Lily Monsen for the photograph.

Mineralogical Museum, Oslo, May 1937.

Table 1.
*Chemical analysis
of Scheteligite from Torvelona, Iveland.*

	0.0	Calculated
CaO	10.73	Ca 187
FeO	1.88	Fe 26
MnO	6.19	Mn 87
Sb ₂ O ₃	7.77	Sb 53
Bi ₂ O ₃	2.54	Bi 11
Y ₂ O ₃ (280).....	6.00	Y 48
} 412 X ₂		
TiO ₂	18.73	Ti 234
Ta ₂ O ₅	20.—	Ta 90
WO ₃ } 33.65 0/0 ...	5.—	W 22
Nb ₂ O ₅ }	8.65	Nb 64
} 410 Z ₂		
Loss on ignition....	2.00	
SiO ₂ 6.00 0/0 calculated as microcline	9.70	O 1396
	99.19	

Formula:



NOTISER

A HANDY SEDIMENT SAMPLER

The sampler leads described by me (K. M. STRØM: A New Sampler Lead. — N. Geol. Tidsskr. 14, 1934, p. 162—166) are too heavy and bulky for use when one is travelling light in order to be able to survey lakes off the beaten track.

They are also somewhat heavy for the light winches one is often compelled to use on board frail freshwater craft.

For the investigation of lakes with very difficult access in Northern Norway during the summer of 1935, I accordingly designed a tube lead for sampling bottom sediments, which turned out to work very well under all conditions. The lead was constructed by Mr. BJARNE ANDERSEN, and replicas may be bought from him. (Chemical Institute, University of Oslo.)

The lead consists of two parts, the brass tube with the bottom valve, and the extra weight, which is slipped down around the top of the tube. The valve construction is the same as previously described (op. cit.), but the valve is detachable from the tube to which it is secured with a bayonet fastening. The inner glass tube is thus extracted downwards from the protecting brass tube, the valve preventing the sediments from slipping out, and there is no need of reversing the lead, as was the case with the earlier construction.

When travelling as light as possible, e.g. when investigating a mountain lake singlehanded with all apparatus in a rucksack, the lead may be worked without the extra weight, and is then very light and compact. The weights are thus apportioned.

Brass tube and valve	865 g
Inner glass tube	95 „
Total weight of lightest outfit	960 g
Extra weight	1 040 „
Total weight as normally used	<u>2 000 g</u>

The total length of the brass tube is 59 cms, its outer diameter 2,8 cms. The glass tube is 50 cms long with an inner diameter of 1.8 cms.

The whole apparatus is illustrated on the figure. It should be noted that the extra weight is cast into the shape of 4 stabilising fins, which guide the tube through the water so that the descent is always vertical.

For travelling, the sampler lead and 20 glass tubes, with rubber stops and quantities of unlimed cotton (for filling the space above the sediments in the glass tubes) are carried in a wooden case. The length of the storage room for the glass tubes is exactly that of the tubes with rubber stops well in, so that there is no need for further securing the stops.

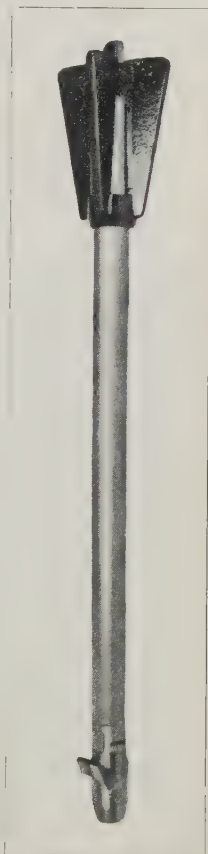
This sampler lead was used in a number of lakes, at depths down to 167 ms, and invariably worked well. Of course a light lead can never perform what can reasonably be expected of a heavy one only, but the glass tubes were as a rule about half filled with rather firm sediments. In looser deposits they would undoubtedly fill completely.

When trying to obtain samples in a land-locked fjord at 346 ms depth this sampler lead proved too light for the weight of wire corresponding to that depth.

Since the ball valve was described by me (op. cit.), I have got information of another sampler lead with a *rideau* shutter below the sounding tube. The shutter is operated by a messenger, and is thus unlike the ball valve unworkable in a seaway, though this sampler seems to be particularly useful in securing very soft muds. (Described by L. W. COLLET: Les travaux du Laboratoire de géologie de l'Université de Genève, sur l'Arve et le Lac de Genève. — Union Générale des Rhodaniens. 3ième Congrès du Rhone. Genève 1929, p. 203—206.)

There has also very recently been published an account of a core sampler, where the sampler tube is fired into the bottom by an explosive charge contained in a kind of gun. (C. S. PIGGOT: Apparatus to secure core samples from the ocean-bottom. — Bull. Geol. Soc. Amer. 47, 5, 1936, p. 675—684.)

Samples of up to 2.6 ms length were obtained in the open sea from depths down to 2300 ms. With such very long samples one usually encounters hard deposits below the softer. There is consequently little need of any valve at all, though the author reports on the loss of one core, which slid out again. In soft deposits a kind of valve would undoubtedly be necessary, and the ball valve is certainly strong enough to be fired into the bottom, as suggested also by me (op. cit.), though I thought of fitting the sampler as a rocket.



In any case the problem of obtaining core samples of the sea bottom long enough for geological studies is now finally solved through the application of Dr. C. S. PIGGOT's gun, preferably together with my ball valve.

Kaare Münster Strøm

NORSK KARTOGRAFISK FORENING

På møte i opmålingsingeniørenes gruppe i Norsk ingeniørforening 10/12 1936 blev det fremsatt forslag om å danne en Norsk kartografisk forening. Forslaget fikk almindelig tilslutning og ca. 50 interesserte tegnet sig foreløpig som medlemmer. Det blev opnevnt et arbeidsutvalg som skulde forberede et konstituerende møte.

Det konstituerende møte blev holdt i Ingeniørenes hus, Kronprinsens gate 17, mandag 8/2 1937. Til møtet var også Norsk geologisk forening innbudt.

Efter foredrag av direktør K. S. KLINGENBERG om den terrestriske stereofotogrammetriske målemetodes bruk i Norge og om forandringer i hovedkartverkets utstyr, blev det vedtatt lover og valgt styre. Formann blev geodet, major FINN BJØRNSETH og sekretær ingeniør B. H. HAGEMAN.

For kartleggende geologer vil naturligvis denne forening være av interesse, og Norsk geologisk forening vil for fremtiden bli holdt underrettet om dens virksomhet. På den annen side vil det være en opgave for geologene å fremholde at en geologisk forståelse av terrenget er nyttig for alle som arbeider med kartlegging.

Red.

LITERATURMELDING OG KRITIKK

NORGES GEOLOGISKE UNDERSØKELSE NYE KART OG BESKRIVELSER

Det er meget gledelig at N. g. u. nu kommer med en serie kart i målestokk 1:100 000 med beskrivelser. Forholdene har medført at slike har vært sjeldne i den senere tid. I de siste 15 år er der utenom 4 av Oslofeltets kart visstnok bare kommet ett slikt, Tysfjord i 1931, uten beskrivelse. Arbeidet har vesentlig vært lagt på det nordlige Norge, hvorfra man har fått 5 kart i målestokken 1:250 000, 4 fra Rekstads, det femte fra Holmsens hånd.

Nu innleder Holmsen med et rektangelkart N. Femund, og Marlow følger efter med Foldal. Dessuten er en del kart dels trykt, dels under trykning.

Dr. Gunnar Holmsens kart og beskrivelse er som ventelig en grei oversikt av en erfaren geolog som behersker alle feltgeologiens disipliner. I betraktning av de svære masser av løse avleiringer har beskrivelsen fått en heldig proporsjon mellom berggrunnsbeskrivelsens og kvartærgeologiens del, og kan forsåvidt tjene som et mønster.

Spørsmålet om en slik kartbladsbeskrivelses forhold til den gjeldende opfatning vil alltid kunne diskuteres. Det vil alltid bli spørsmål om man skal skrive at noget er skjøvet over, eller nøie sig med å fastslå at det ligger over. Personlig vilde jeg i en kartbladsbeskrivelse foretrekke det siste, selv om jeg er enig i Holmsens opfatning.

Wolmer Marlows kartbladsbeskrivelse Foldal er av en noget annen art. N. g. u. er selvfølgelig selv herre over hvilke av sine medarbeidere den vil gi æren for publikasjonene. Men når beskrivelsen er på 104 sider, hvorav Marlow har skrevet de 19, er det noget misvisende at ikke herrene Streitlien, Aasgaard, Riiber, Theting og vel også Gunnar Holmsen har fått sine navn anført på titelbladet.

Verre er det at den del av beskrivelsen som er skrevet av Marlow, berggrunnsbeskrivelsen, ikke på nogen måte svarer til den standard N. g. u.s publikasjoner bør ha, og i det vesentlige har hatt til idag.

Beskrivelsen skjemmes av mange trykkfeil og skrivfeil. Selve sprogformen er ofte slik at teksten virker uklar. Dette henger sammen med manglende kjennskap til terminologien. Når man lar kalkstenen optre i ganger, eller lar biotitt optre sideordnet med glimmer, er det ikke bra. En praktblomst forekommer på s. 24. Her regnes sparagmitten til „de livløse formasjoner“, mens skifrene i Foldal er „bergarter,

hvor de første spirer til liv har begynt å utvikle sig, og altså må tilhøre den kambrosiluriske formasjon". Selv om man vil gjøre sparagmitten til prekambrium bør man betenke sig noget på å gjøre den eldre enn alt liv. Og et lite studium i en elementær lærebok vil overbevise en om at kambro-silur omfatter tre geologiske formasjoner, kambrium, ordovicium og silur. Det vil også fremgå av en slik lærebok at uttrykket formasjon ikke kan brukes om en skiferavdeling eller en gruppe, således som Marlow gjør s. 25.

Billedstoffet virker nærmest latterlig. Bjørnehi, bølgende enger, fosser eller utsikt over Rondane er vakkert å se på. Men i et arbeide om petrografi, stratigrafi og tektonikk vilde mikrofotografier av noen av „prøvekolleksjonens“ 339 tynnsnip eller noen profiler vært av ulike større betydning.

Når Marlow hevder en annen opfatning enn N. g. u.s gamle medarbeider K. O. Bjørlykke med hensyn til den bergart i kartets sydøstre hjørne, som hos Marlow kalles sericittkvartsitt og sericittskifer, kunde man vente å finne en begrunnelse for dette, og en nærmere beskrivelse av bergarten. Bjørlykke regner denne bergart, efter adskillige overlegginger, til „de krystallinske Rørosskifere i nord“, mens Marlow oppfatter den som en forandret sparagmitt, uten å føre noget bevis for denne opfatning.

Mindre og større teiger av „sericittkvartsitt“ fins mange steder inne i de forskjellige glimmerskifre. Bjørlykke oppfatter disse som kvartsrike partier i glimmerskifrene. Dette står i samklang med erfaringer fra andre områder. Marlow forklarer en av dem som et „øie“ i skiferen, og antar at den er blitt bøiet op og klemmt inn mellem skiferlagene. Nogen av de andre beskrives som „kvartsittbergart, hvori finnes innleiret adskillig meget¹ av småbladet sericitt. Disse kvartsitter må sannsynligvis være omvandlede trondheimitter“. Det ligger nær å spørre efter en motivering for en slik opsiktvekkende påstand.

Flere steder nevnes at Tronfjellets gabbrobergarter har kontakt-metamorfosert de omgivende bergarter. Også her ligger det nær å be om en beskrivelse av de angivelig kontaktmetamorfoserte bergarter. Er det funnet hornfelser heroppe vil det ha en ganske vidtrekkende betydning.

Det kanskje viktigste moment i den stratigrafiske betraktning er ikke utnyttet. Konglomeratet ved Høstas utløp i Folla og i Brekkebekkdalen er ikke beskrevet, så man vet ikke hvad det er. P. A. Øyens og Hedstrøms undersøkelser om kleberstenskonglomeratet fra Otta nevnes ikke. Heller ikke nevnes Bjørlykkes opfatning av Foldakonglomeratets alder og stratigrafiske posisjon. Efter Øyens fossilfunn og efter de opplysninger som foreligger fra andre trakter om kambro-siluriske konglomerater skulde det være all grunn til å bruke et slikt konglomerat ved betraktninger over stratigrafien. Det er i det hele påfallende at Bjørlykke

¹ Uthevet her.

i 1905 skrev mere utførlig og kom til sikrere resultater enn Marlow 30 år senere.

Det er flere ting i arbeidet som det kunde være grunn til å hefte sig ved. Men det her anførte får tjene som en karakteristikk.

At et begynnerarbeide har en del feil og mangler er ganske rimelig. Trykningen har vel også foregått efterat Marlow hadde forlatt N. g. u., hvad der kan ha medført adskillige ulemper. Hvis det hadde vært et arbeide som bare stod for Marlows personlige regning, hadde det kanskje ikke vært så stor grunn til å ta fatt på det. Men i det øieblikk det dreier sig om en publikasjon som både efter sin art og sitt utstyr har en offisiell karakter, er det grunn til å spørre hvorledes et arbeide av denne kvalitet kan komme frem. I et slikt tilfelle har institusjonen ikke bare adgang til, men også plikt til å sørge for at publikasjonen blir som en slik skal og bør være.

Alt som trer frem for offentligheten, også norsk geologisk forskning og dens offisielle eksponent N. g. u., vil lett bli bedømt efter sin svakeste prestasjon. Og ingen av dem er tjent med at det på bakgrunn av Marlows arbeide reises tvil om N. g. u.s vilje eller evne til å drive geologisk forskning.

Niels-Henr. Kolderup.

*

Det har ganske naturlig vakt oppmerksomhet, at Norges geologiske undersøkelse i sin publikasjonsserie har utgitt et arbeid som kvalitativt ligger utenfor hvad vi er vant til å finne i denne serie og hvad vi venter å finne i en publikasjon fra en offentlig faginstitution.

Da en kritikk av dette arbeid fører inn på spørsmålet om de generelle prinsipper for landets kartlegging og utforskning, har redaksjonen oversendt Kolderups manuskript til Norges geologiske undersøkelse, for at et eventuelt svar kan bli trykt i samme hefte av tidsskriftet.

Som svar er mottatt følgende:

BEMERKNINGER TIL NIELS-HENR. KOLDERUPS KRITIKK AV WOLMER MARLOWS KARTBESKRIVELSE

Foranstående anmeldelse er forelagt mig til gjennemsyn og eventuell uttalelse.

Det kan opplyses at Marlow i en årrekke arbeidet på Foldalsbladet. Ved hans plutselige utnevnelse til sysselmann stod man overfor valget enten å la alt innsamlet materiale ligge og bare utgi kartet eller også å imøtekomme hans ønske om å få utgi sine resultater, selv om dette måtte foregå i all hast, fordi han skulde ha siste båt til Svalbard.

Om kartbladsbeskrivelser i almindelighet bemerkes, at man vanligvis legger disse an således at de kan forstås av alle. Dette er overensstemmende med det som gjøres i andre land. Særlig bør det redegjøres for det som man har funnet er av økonomisk betydning.

Av videnskapelige resultater medtas det som forfatteren skjønsmessig synes bør medtas, mens det mest videnskapelige forbeholdes spesielle monografier. Det er derfor ikke almindelig å finne mikrofotografier o. l. i disse beskrivelser. Marlows billedmateriale er ikke særlig forskjellig fra det som man ellers finner i kartbladsbeskrivelser.

Marlows innsamlinger foreligger for senere bearbeidelse i vel ordnet stand. Man må altså vente, at når kartleggingen er tilstrekkelig langt fremskredet vil det komme en monografi over et større område, hvor vedkommende forfatter ikke er bundet innenfor et kartblads ramme.

Det lar sig ikke nekte at det er beklagelige feil ved beskrivelsen, men det virker tendensiøst når Kolderup, vel bekjent med ovennevnte spesielle arbeidsforhold, kritiserer som opfatningsfeil det som en opmerksom lesar må opfatte som skrivfeil og til dels muligens trykkfeil. Når Marlow f. eks. har skrevet „Kalkstensgang“, så fremgår det klart av innholdet at han mener den samme forekomsttype som de kalkstenslag som er nevnt 7 linjer ovenfor.

At glimmer er skrivfeil for sericitt, som ofte er nevnt, vil de fleste forstå. Jeg nevner bare disse skrivfeil for å vise at den chance som her var for en lettkjøpt kritikk er utnyttet noget vel langt.

At dr. Kolderup av disse 19 sidene trekker slutninger om N. g. u.s. „evne og vilje“, gir uttrykk for en ganske spesiell innstilling.

Oslo, den 7. april 1937.

Carl Bugge.

NORSK GEOLOGISK FORENINGS VIRKSOMHET

GENERALFORSAMLING OG MØTE TORSDAG 11. FEBRUAR 1937

Til stede 24 medlemmer.

Årsmelding for 1936.

Siden forrige generalforsamling er utgått 1 medlem:

KNUT WILLOCH, utmeldt fra 1/1 1937.

I samme tidsrum er innvalgt 2 nye medlemmer:

ANDERS KVALE, cand. real., Bergens museum, Bergen. 6. februar 1936.

KRISTOFFER STENVIK, laboratorieassistent, Geologisk museum, Oslo.

12. mars 1936.

Medlemstallet er 117, hvorav 1 æresmedlem, 38 livsvarige og 78 årsbetalende.

Det er i 1936 holdt 6 ordinære møter med et samlet medlemsfrem-møte av 114. En planlagt ekskursjon til Alnsjøfeltet ved Oslo støtte på flere hindringer og blev til slutt opgitt, da det blev for sent på høsten. Den vil bli tatt op igjen til sommeren.

Av tidsskriftet er utkommet bind 16, hefte 1. Hefte 3—4 vil snart bli utsendt. Oplaget er som før.

Utdrag av regnskap for 1936.

I. Det ordinære budgett.

Inntekt.

Beholdning overført fra 1935	kr.	171,30
Innkomet medlemskontingent	„	627,84
Tilskudd fra stat	„	400,00
Tilskudd fra Sulitjelmafondet	„	3 500,00
Ekstraordinært tilskudd fra Nansenfondet til A. Monsen:		
Graptolithenfauna, bd. 16	„	1 000,00
Salg av særtrykk	„	42,34
Renter av bankinnskudd for 1936	„	73,34

Kr. 5 814,82

Utgift.

Tidsskriftet:

Trykning, klisjeer og ekspedisjon, Bd 16	kr. 1 695,26	
Arbeidshjelp	" 58,00	
Bokhandlerrabatt, porto, skrivesaker	" 67,07	
		kr. 1 820,33
Reuschmedaljen	" 3,00	
Representasjon, møter	" 197,85	
Beholdning overført til 1937	" 3 793,64	
		kr. 5 814,82

II. Livsvarige medlemmers fond.

Urørlig kapital.

Overført fra 1935	kr. 3 215,00
Innkomet kontingent for 2 medlemmer	" 200,00
	kr. 3 415,00
Hvorav statsobl. kr. 3 000,00, i bank kr. 415,00.	

Disponible renter.

Overført fra 1935	kr. 686,50
Renter av statsobligasjoner, 1936	" 140,00
Renter av bankinnskudd	" 27,91
	kr. 854,41
Fragår omkostn. ved kjøp av statsobl.	kr. 2,50
Avgift for forvaltning av statsobl.	" 5,00
	7,50
	kr. 846,91

Status pr. 15/1 1937.

Livsvarige med-	{	Kapital	kr. 3 415,00
lemmers fond		Opsparte renter	" 846,91
			kr. 4 261,91
Utestående medlemskontingent		" 500,00	
Beholdning, ordinære budgett		" 3 793,64	
			kr. 8 555,55

Regnskapet er revidert av H. H. SMITH.

Valg av styre for 1937.

Formann	T. BARTH
Sekretær	S. FØYN
Redaktør	H. ROSENDAHL
Styremedlemmer	I. OFTEDAL
	H. BJØRLYKKE
Varamann	K. O. BJØRLYKKE

Reuschmedaljen.

På styremøte 12. desember 1936 blev det, overensstemmende med komiteens innstilling, besluttet å tildele dr. philos. LEIF STØRMER Reuschmedaljen for hans arbeid „Contribution of the geology of the southern part of the Oslofjord. The rhomb-porphry conglomerate with remarks on younger tectonics“, trykt i Norsk geol. tidsskr. 15, 1935. Komiteen uttaler at nevnte arbeid oppfyller på alle måter betingelsene for tildeling av Reuschmedaljen.

Til medlemmer av Reuschmedaljekomiteen for 1937 blev valgt C. BUGGE og L. STØRMER.

På medlemsmøtet efter generalforsamlingen blev det først holdt et innledningsforedrag av

G. HOLMSEN: *Kartlegging av løse avleiringer.*

Våre geologiske kart er fortrinsvis berggrunnskart. Det er berggrunnens art og utbredelse de har for øie, og dens bygning de har villet utrede. De løse avleiringer, jordartene, har derfor på våre offisielle geologiske kart fått en stedmorlig behandling til tross for at også kjennskapet til disse er av den største kulturelle og praktiske betydning.

Mens vi således i løpet av de årrekker Norges geologiske undersøkelse har vært i virksomhet, har fått 2 sett av oversiktskart over vårt lands berggrunn, kan vi ikke idag, med selv de beskjedneste krav til pålitelighet fremstille et tilsvarende oversiktskart over de løse avleiringer på grunnlag av det materiale vår kartlegging i målestokk 1 : 100 000 inneholder.

Årsaken hertil synes å være at kravene til kartets fremstilling av bergbygningen nu er så vidt store at en og samme geolog ikke lenger kan beherske så vel de løse avleiringers kartlegging som berggrunnens.

I sitt budgettforslag for terminen 1936—37 foreslo derfor direktøren for N. g. u. en bevilgning til å begynne en spesiell geologisk kartlegging av de løse avleiringer over berggrunnen. Målet med denne skulde være å innsamle materiale til fremstilling av et oversiktskart.

Det blev overlatt til mig å planlegge og iverksette dette arbeide, og det er for å gi en meddelelse om den første sommers resultater jeg i aften har bedt om ordet i N. g. f.

Som assistenter for sommeren blev engasjert dosent Isachsen, cand. real. Samuelsen og de realstuderende Åge Kjellerød og Per Holmsen. Efter et 3 dagers instruksjonskursus i traktene fra Lier til Åmot og videre over Lyngdal og Numedal til Bolkesjø blev assistentene overlatt hver sitt område. De vil hver for sig senere i aften gi en kort meddelelse om resultatet av sitt arbeide med jordartkartleggingen.

Kartleggingen utføres på grunnlag av de topografiske kart i målestokk 1 : 100 000.

Følgende gradteiger blev i år tegnet ferdig: Flesberg, Dagali og Mår. Dessuten blev utført mere eller mindre arbeid på bladene Eiker, Nore og Tunhovd samt på rektanglene Sarpsborg og Gran.

Inndelingsgrunnlaget for jordartenes klassifikasjon på kartverket danner deres genesis. Der skjelves mellom havavleiringer, innsjø- og elveavleiringer som får hver sin farve. Den form hvorunder avleiringer opptrer, så vel som til en viss grad også dens kornstørrelse, fremstilles ved hjelp av konvensjonelle tegn. De sedentære avleiringer torvjord og lynghumus („råhumus“) slås sammen til én farvebetegnelse. Forvittringsjord får sin egen farve, ur sitt tegn. Av bregrus skjelves mellom lerholdig og sandholdig uten at ennå noen norm er fastsatt for skillet mellom de to grupper. Blokkrikdom antydes ved et eget tegn.

Hvis bregrusdekket er tynt og berget ofte stikker frem, avmerkes dette ikke med bregrusets dekkfarve, men med striper av bregrusets farve. På samme måte avmerkes berggrunn dekket av torvjord med stripning på områder hvor torvdekket ligger spredt i små myrsøkk hvor det vilde være uoverkommelig å kartlegge detaljene så vel som hvor lyngtorv og »råhumus« danner et tynt dekke direkte på berggrunnen hvori trærnes røtter finner feste. Dette system er elastisk og tillater flere kombinasjoner. Kun i de tilfelle hvor berggrunnen er blottet for bregrus, forvittringsjord eller lynghumus over så store arealer at de kan gjengis uten overdrivelse av utstrekningen, avlegges blottet berggrunn på kartverket. Når vi har høstet erfaring nok er det meningen å innføre nærmere definerte grenser av den klassifisering som her forsøksvis er tatt i bruk.

Grustak med snitt gjennom de løse avleiringer avmerkes, likeså forekomster av skjellsand, kalktuff og kiselgur. Assistentene fører dagbok og innleverer til N. g. u. kart over sine reiseruter. Dette kart over dagsmarsjene letter i høy grad arbeidet med å finne frem til deres notater vedrørende en bestemt egn.

Derefter gav G. Holmsens medarbeidere F. ISACHSEN, A. SAMUELSEN, stud. real. ÅGE KJELLERØD og stud. real. PER HOLMSEN meddelelser om resultatene av sommerens kartlegging av løse avleiringer på de kartblad som var tatt under arbeid, gradteigbladene Hallingskarvet, Dagali, Tunhovd, Flesberg, Eiker, Mår, Nore samt rektangelbladene Gran og Sarpsborg.

I diskusjonen efter foredragene deltok H. Bjørlykke, K. O. Bjørlykke, A. Bugge, C. Bugge, S. Foslie og G. Holmsen.

K. O. BJØRLYKKE foreslo å fortsette diskusjonen om dette emne på et senere møte.

MØTE TIRSDAG DEN 16. MARS 1937.

Til stede 19 medlemmer og 1 gjest.

H. ROSENDAHL gav følgende meddelelse om den internasjonale kvartærgeologiske kongress. —

Som det blev meddelt på møtet 5. november 1936, blev det på siste INQUA-kongress i september 1936 i Wien besluttet å foreslå neste kongress holdt i England. Om dette ikke lot sig gjøre var de fennoskandiske land villig til å påta sig hvervet. Det er nu kommet avslående svar fra England. Dermed er det avgjort at neste kongress blir holdt i Fennoskandia

i 1940 med Stockholm som møtested og med ekskursjoner i Sverige, Finnland og Norge.

ANDERS KVALE: *Et kaledonisk intrusiv- og effusivfelt i Sunnhordland.*

Et arbeide om emnet blir trykt i Bergens Museums Årbok 1937.

I diskusjonen deltok T. Barth, H. Rosendahl, N. H. Kolderup, O. Holtedahl, foredragsholderen.

K. O. BJØRLYKKE: *Om et oversiktskart over de løse jordlag i Norge.*

For ca. 1 1/2 år siden gav jeg her i foreningen en kort „oversikt over pedologiens nuværende stilling og dens forhold til geologien“. Jeg uttalte da i slutningen av foredraget at „i andre land går utviklingen tydelig i retning av et utvidet jordbunnsstudium og jordbunnskartlegging ved utdannede spesialister som er tilknyttet en fast stilling i vedkommende lands geologiske undersøkelse“ og jeg endte foredraget med, at det er „da et spørsmål om man ikke også bør innrette sig på lignende vis hos oss“.

I den påfølgende korte diskusjon nevnte direktør Bugge at det kanskje burde nedsettes en komité og jernbanegeolog Rosenlund krevde at det burde fremsettes en bestemt plan. Professor Holtedahl foreslog at man først burde konferere med landmennene om det var stemning for en sådan jordbunnskartlegning hos oss.

Dermed var saken avsluttet for den gang.

Det reiste spørsmål om jordbunnskartlegning kom op igjen i en noe endret form i foreningens forrige møte, den 11. februar i år, hvor statsgeolog Gunnar Holmsen og noen av hans medarbeidere holdt foredrag om „Kartlegging av løse avleiringer“. Diskusjonen herom måtte utsettes på grunn av den knappe tid.

Når den nu i dette møte skal fortsette synes jeg emnet må forenkles og nærmere begrenses til det som jeg synes for tiden er mest påkrevet, nemlig *utarbeidelse av et oversiktskart over de løse jordlag i vårt land*. Det er nemlig aktuelt for tiden, da man driver på med bureising og opdyrking av de store dyrkbare vidder som vi skal ha, men som ingen vet riktig hvor er.

„Kartlegging av de løse avleiringer“, som tittelen var i forrige møte, er så altfor omfattende. Det er heller ikke noe nytt. Det er minst like så gammelt som den geologiske undersøkelse. Kjerulf gjorde det første skritt ved sine jordbunnskart over de viktigste strøk på Østlandet og sitt oversiktskart over den glasiale formasjon i den sydlige del av Kristiania stift. Også på hans geologiske kart over det sønnenfjelske Norge i målestokken 1 : 400 000 av 1866 er de løse jordlag avsatt på en for den tid tilfredsstillende vis. Etter 1879 gikk man som bekjent over til utgivelse av geologiske rektangelkart, hvor også de løse jordlag blev avsatt når de optrådte i større masser eller som formasjon; men ofte blev de løse avleiringer satt uten farve på kartene og betegnet som: sand-aur, fjellmarkens fylninger, moréner. — Betegnelsen „fjellmarkens fylninger“ var lettvinnt, men lite oplysende. Kartene fikk også et urolig og uferdig preg ved de mange farveløse flekker og partier. (Disse farveløse flekker er forresten forlatt på de senere rektangel- eller gradavdelingskart.)

Det neste forsøk på spesielle jordbunnskart blev foretatt av dr. Reusch, da han etter Kjerulfs død i 1888 blev bestyrer av den geologiske undersøkelse. Han opstillet som egen post på sitt program for den geologiske undersøkelses arbeider i 1889: „Oprettelse av agronomiske kart over viktigere jordbruksegne“ og overlot dette arbeide til landbruksingeniør Grimnes, Jæren, landbruksingeniør Blakstad, Trondheims omegn og landbruksskolebestyrer Sendstad, Oslo omegn.

Men disse utmerkede menn var ikke jordbunnesspesialister, og stor-tingets landbrukskomité uttalte i 1895 at alt arbeide med jordbunnskart-legging burde stanses av N. g. u. og overlates til den private eller halvoffentlige foretaksomhet.

I henhold hertil fikk jeg i 1908 „det Kgl. selskap for Norges vel“ til å nedsette et „jordbunnsutvalg“ med det formål „å fremme undersøkelser over jordbunnen, jordens kultur og utnyttelse samt vareta de interesser som derved står i forbindelse“. Utvalgets arbeide blev i 1921 overdradd til staten og knyttet til det geologiske institutt ved Landbruks-høiskolen under tittel av „Statens jordundersøkelse“. Også dette tiltak led av den mangel, at arbeidet for størstedelen måtte foregå som ferie- eller biarbeide av unge menn som neppe kunde betegnes som spesialister og som for resten så snart som mulig søkte sig over i faste livsstillinger.

Det var på grunnlag av disse erfaringer og jordbunnslærens betydelige utvikling som en særegen videnskapsgren i den senere tid, at jeg holdt mitt forrige foredrag her i foreningen og da bl. a. pekte på hvorledes man hadde innrettet sig i andre land, eksempelvis med en egen avdeling for agrogeologi (som i Finnland) eller med fastlønnede jordbunnesspesialister ved den geologiske undersøkelse (som i Sverige og Preussen). Hvorledes man best burde innrette sig i vårt land opstillet jeg bare som et spørsmål til overveielse. Men skulde jeg uttale min personlige mening, så er den at Norges geologiske undersøkelse med sitt nuværende personale neppe kan gi sig i kast med utarbeidelse av moderne jordbunnskart. Dertil trengtes i tilfelle ansettelse av en eller flere jordbunnesspesialister.

Derimot mangler undersøkelsen ikke kvartærgeologer og det vilde derfor ligge nær, at disse skaffer oss et kvartærgeologisk oversiktskart over vårt land. Et sådant er meget påkrevet for at vi kan kjenne og demonstrere vårt lands jordrikdom eller kanskje rettere jordfattigdom. Jeg har selv arbeidet adskillig med dette spørsmål, men det har sine vanskeligheter. Det heter imidlertid at vanskelighetene er til for å overvinnes.

Oversiktskartets formål måtte være å gi oss en oversikt over hvad vi har i vårt land av løse jordlag og hvilken rolle disse spiller i vårt lands økonomiske liv. Vi vet jo av statistikken at kun litt over 3 % av vårt lands overflate er opdyrket — og vi antar at et omtrent likeså stort areal av våre løse avleiringer kunde opdyrkes og føres over til kulturjord. Men beliggenhet og beskaffenhet av disse udyrkede vidder kjenner vi lite til. Et kvartærgeologisk oversiktskart vilde kunne hjelpe oss til dette — til altså å kjenne vårt land. Fra dette synspunkt måtte kartet planlegges.

I henhold hertil måtte det på kartet utskilles følgende led:

1. Dyrkningsjord, det vil si de strøk hvor de løse jordlag har en tykkelse av minst 20 à 30 cm, så jorden i opdyrket stand kunde pløies og dreneres.

Hvor jordlagene er mindre dype eller hyppig avbrytes ved opstikkende fast fjell kunde de betegnes som:

2. Skogbunnsgjord, som kunde anvendes til skogsmark på dertil egnede steder.

Som en tredje kategori kunde opføres:

3. Den bare fjellgrunn eller snaufjell.

Som en fjerde kategori måtte sannsynligvis også opføres fjellviddene, som ligger så høit over havet at de hverken egner sig til opdyrking eller til skog, men i høiden kun til beite. De kunde betegnes som:

4. Høitliggende beitestrøk og høifjell.

Disse fire sorter kunde betegnes med særegne farver. Jordartenes navn og beskaffenhet vilde være av mindre betydning for oversiktskartet, men de vilde i nogen grad kunne fremgå av beliggenheten og høiden over havet, og de kunde betegnes med sorte prikker for sandjord, små ringer for morénejord og streker for myrjord, lerjord uten sorte tegn. For å angi beliggenhet og stofflige egenskaper kunde kartet forsynes med angivelse av den marinegrense eller iallfall likehevningsslinjene (isoanabasene), i likhet med Rekstads kart over landets heving efter istiden (N. g. u. skr. nr. 96).

Derved fikk man adskilt det tidligere submarine terreng med vesentlige marine avleiringer og det tidligere supramarine terreng med vesentlig moréneavleiringer. Å få avsatt myrene overalt vilde vel vanskelig la sig gjøre på et oversiktskart i liten målestokk.

Ja så kommer vi til oversiktskartets målestokk. Der er flere målestokker å velge mellom. Jeg er blitt stående ved det gamle geologiske oversiktskarts i målestokken 1 : 1 000 000.

Kjerulfs gamle oversiktskart fra 1878 er et rent fjellgrunnskart. De løse jordlag er ikke avmerket, men står som hvite flekker. Det kunde vel da ikke være for tidlig om vi nu i 1937 eller 1938 — efter 60 års forløp — fikk et oversiktskart i samme målestokk over de løse jordlag i vårt land.

Finnland fikk allerede for 40 år siden både et fjellgrunnskart og et kvartærgeologisk, oversiktskart i målestokken 1 : 2 000 000 utarbeidet av Sederholm.

Hvis den her skisserte plan godtas kunde man straks påbegynne arbeidet med utarbeidelsen av det kvartærgeologiske oversiktskart ved å overføre de løse jordlag fra de foreliggende ferdige kart til oversiktskartet, hvor de kunde betegnes som dyrkningsjord eller kvartære formasjoner av betydelig mektighet og utstrekning. Vanskeligere blir det naturligvis å avgrense skogbunnsgjorden og snaufjellet, mens høifjellsviddene vel kunde avsettes mere lettvtint.

Et oversiktskart må nødvendigvis bli noget skjematisk og kan ikke gjøre krav på full nøiaktighet i alle detaljer.

Det er de store linjer og oversikten man må søke å få frem.

Til et sådant oversiktskart burde også knyttes en beskrivelse som gav en nærmere utredning om de kvartære dannelser i vårt land. I denne

beskrivelse vilde det til slutt også kunne bli plass til en oversikt over jordmonnets variasjoner i de forskjellige jordbunnsregioner og jordbunnsprovinser i vårt land, som allerede er påvist eller som blir påvist under kartets utførelse. Noget tilsvarende har man allerede i Finland i Sederholms lille avhandling fra 1909 „Om Finlands jordarter“. Det er for resten kommet meget nytt til i den senere tid.

Den rent agronomiske del kunde overlates til „Statens jordundersøkelse“ ved Landbrukshøiskolen, hvis arbeidet der blir fortsatt som påbegynt.

For fullstendighets skyld bør jeg imidlertid gjøre opmerksom på at navnet Jordbunnskart er lite eksakt. Det er flere sorter jordbunnskart. De viktigste typer tør være:

1. Kart over de løse jordlag. Da disse hos oss er dannelser fra kvartærtiden, tør den riktigste benevnelse være: kvartærgeologiske jordbunnskart.

2. Så har man agronomiske jordbunnskart, hvor hovedvekten er lagt på matjorden eller jordsmonnet og dens skikkethet for kulturplantene.

3. Endelig har man de moderne pedologiske jordbunnskart basert på studiet av jordprofilen og hvor man altså får med både undergrunnsjordens og jordsmonnets egenskaper samt dets betydning for planteproduksjonen.

De kvartærgeologiske kart bør helst utarbeides av kvartærgeologer, de agronomiske av agronomer og de pedologiske av spesialister i jordbunnsforskning. Da N. g. u. hittil ikke har noen faste funksjonærer som er agronomer eller spesielle jordbunns eksperter, kan man for tiden kun vente at den gir sig i kast med kvartærgeologiske jordbunnskart.

Jeg vil avslutte denne innledning til diskusjon om jordbunnskart med å citere prof. Sederholms innledning til hans skrift „Om Finlands jordarter“ av 1909. Han sier:

„Sammenfatningen av alt det som er oss mest dyrebart kaller vi vårt land, vår fosterjord. Men ikke bare i ideell mening, men også i ren økonomisk henseende er et folks dyrebareste eiendom dens jord, nærmere bestemt jordsmonnet. Hverken fjellets malmer, stenkul eller andre forekomster av verdifulle mineraler kan endog tilnærmelsesvis i verdi opveie det øvre tynne jordlag hvorfra plantene suger sin næring og som direkte eller indirekte gir menneskene deres føde.“

I diskusjonen deltok G. Holmsen, O. Holtedahl, F. Isachsen, H. Rosen-dahl, A. L. Rosenlund, H. Bjørlykke, A. Samuelsen og innlederen.

H. ROSENDAHL innvendte, at efter de prinsipper foredragsholderen foreslo fikk man visstnok et nyttig og påkrevet økonomisk jordbrukskart men ikke noget kvartærgeologisk kart. Høitliggende beitestrøk er ikke noget geologisk begrep. Skulde man kartlegge efter vekstgrenser måtte man ikke bare skille ut de områder som ligger høit i fjellet, men også de som ligger langt nord. Derved kommer ensartede geologiske formasjoner til å skilles ut fra hverandre på kartet, og man opnår det motsatte av hvad et geologisk kart skulde vise. En bunnmoréne er geologisk sett samme formasjon enten den ligger på Hedmark, Hardangervidda eller i Finnmark.

THE EO-CAMBRIAN SERIES OF THE TANA DISTRICT, NORTHERN NORWAY

BY

SVEN FØYN

WITH 51 FIGURES IN THE TEXT AND 5 PLATES

Introduction.

The main features of the geology of Finnmark have been elucidated by O. Holtedahl (1918). His excursions in Finnmark during the Summers of 1914—1917, he states, have mainly had the character of a general survey, with the exception of the map sheet Alta in West Finnmark, and in parts the map sheet Nesseby on the Varangerfjord, which districts have been more thoroughly investigated. In his paper of 1918 Holtedahl assumes that the "Sandstone divisions of Finnmark" are younger than Cambrian, mostly because the Porsanger sandstone south of the Porsangerfjord lies apparently conformably above the Lower Cambrian Hyolithus zone. Meanwhile, on his studies of the sparagmite of central Southern Norway, he became aware of great similarities between the "Sparagmite division" and the "Sandstone divisions of Finnmark". In 1929, he again travels through Finnmark (Holtedahl, 1931), and, as he finds that the Porsanger sandstone is separated from the Hyolithus zone by thrust plane, he states that most probably the Finnmark sandstone and the Sparagmite division are synchronous deposits, i. e. of Eo-Cambrian age.

In his paper of 1931, Holtedahl points out that a more detailed examination of the geological conditions in the environments of the upper part of the Tanafjord would largely contribute to a correct statement of the age, and to the knowledge of the glacial conglomerates of Finnmark. I was entrusted with this commission as in 1933 he organized geological research in Finnmark; I am giving herein the results of my work there during the Summers of 1933 and 1934. The financial support for the field investigations was granted by the Nansen Fond and Statens Forsknings Fond.

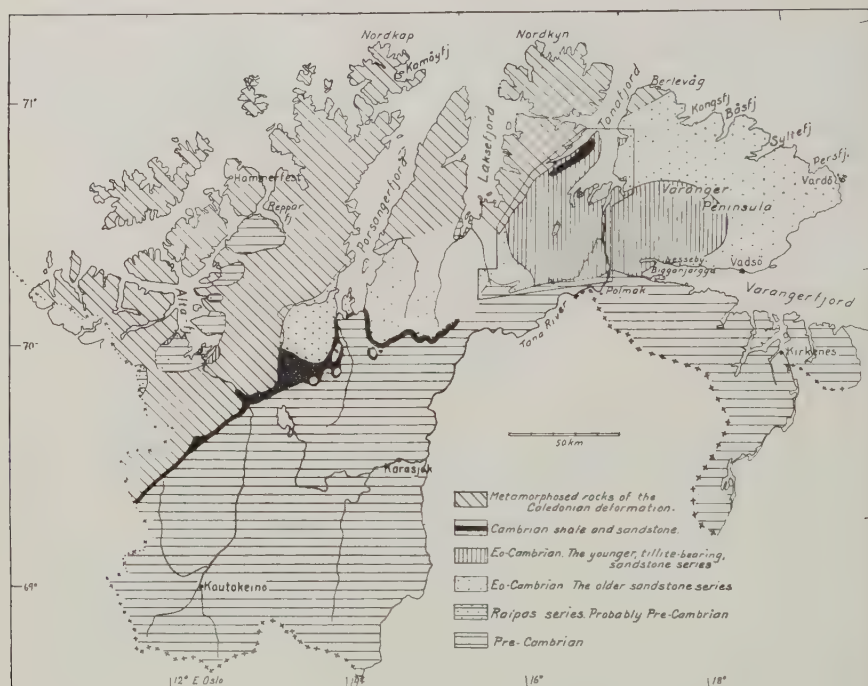


Fig. 1. Geological map of Finnmark.

The bulk of the work has been concentrated on the stratigraphical development, horizontally as well as vertically. Special study has been devoted to the tillites and their relation to the adjacent parts of the sequence. The study of the variations horizontally has involved investigations over a rather extensive area; I therefore had to abandon many detail investigations which would have been desirable. As the greater part of the area was desolate territory, I have only in a few cases had the opportunity of visiting the localities more than once.

The tectonics have only been studied in connection with the stratigraphy, and phenomena which are of little or no importance to the knowledge of the rocks or to the mapping, have had to be omitted.

As to literature published earlier than 1918 on the rock formations of Finnmark, I would refer to Holtedahl's paper of 1918. Later publications have been given by H. Reusch (1923), Th. Vogt (1929), O. Holtedahl (1931), H. Rosendahl (1931).

I would like to take this opportunity of expressing my sincere thanks to Professor Høltedahl for entrusting me with this work and for the valuable assistance he has given me during its preparation. His understanding and ability to inspire his pupils have made my university days a period of my life which I shall always look back upon with only the most pleasant memories.

I. The Stratigraphical Sequence.

About	200 m.	Greyish white quartzitic sandstone.
»	200 »	Shales and fine-grained sandstone, fossiliferous.
»	400 »	Light-coloured quartzitic sandstone, with zones of dark-coloured arenaceous shale.
»	550 »	Green siltstone.
»	200 »	Red quartzitic sandstones, with zones of greenish-grey arenaceous shale.
»	135 »	Shale. Upper part blue-green, lower, about 25 m red-violet.
Max.	40 »	Dark-coloured shale and light-coloured sandstone. Variable thickness.
»	60 »	Upper tillite. Variable thickness.
»	400 »	Red and brown sandstones and red and green shales. Variable thickness.
»	60 »	Lower tillite. Variable thickness. Unconformity.
About	1200 »	Light-coloured quartzitic sandstones and dark-coloured arenaceous shales. "The older sandstone series".

A. The Older Sandstone Series on the Tanafjord.

The quartzitic sandstones make up the greater part of the series. Bed thickness 10 cm to 50 cm. Colours are white, reddish or grey. Quartz is the predominant constituent; the grains are rounded or subangular, on the average 0.2 mm in diameter. Subordinately occur, microcline, plagioclase, mica, zircon, and tourmaline.

The zones of arenaceous shale consist most often of thin layers of sandy or clayey material alternately, the rocks, there-

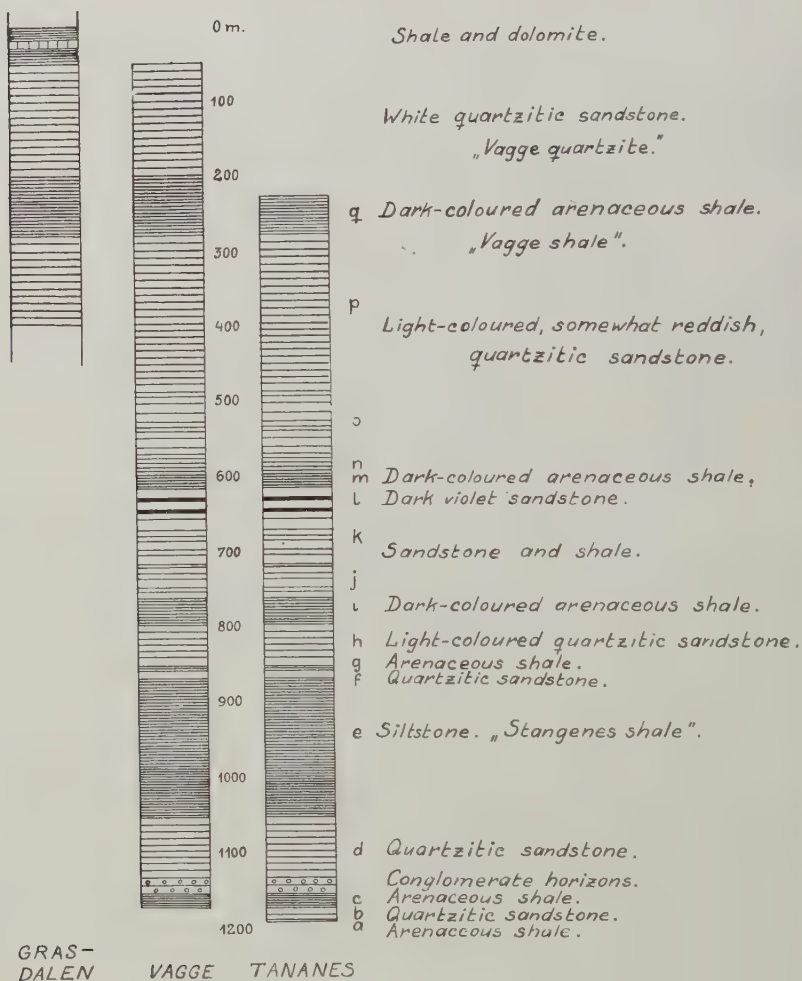


Fig. 2.

fore, easily splitting along the bedding planes. The thickness of the sandy layers varies from 1 mm and upwards. The clayey material gives the shale zones a dark colour, which is contrasting to the light-coloured sandstones described above. The constituents of the sand layers are quartz, biotite, muscovite, subordinate occur, felspar, chlorite, zircon, and iron ore. Grain diameter about 0.1 mm.

Thin bedded quartzitic sandstones, and slaty micaceous sandstones, occur in the zones of both kind of types described above.

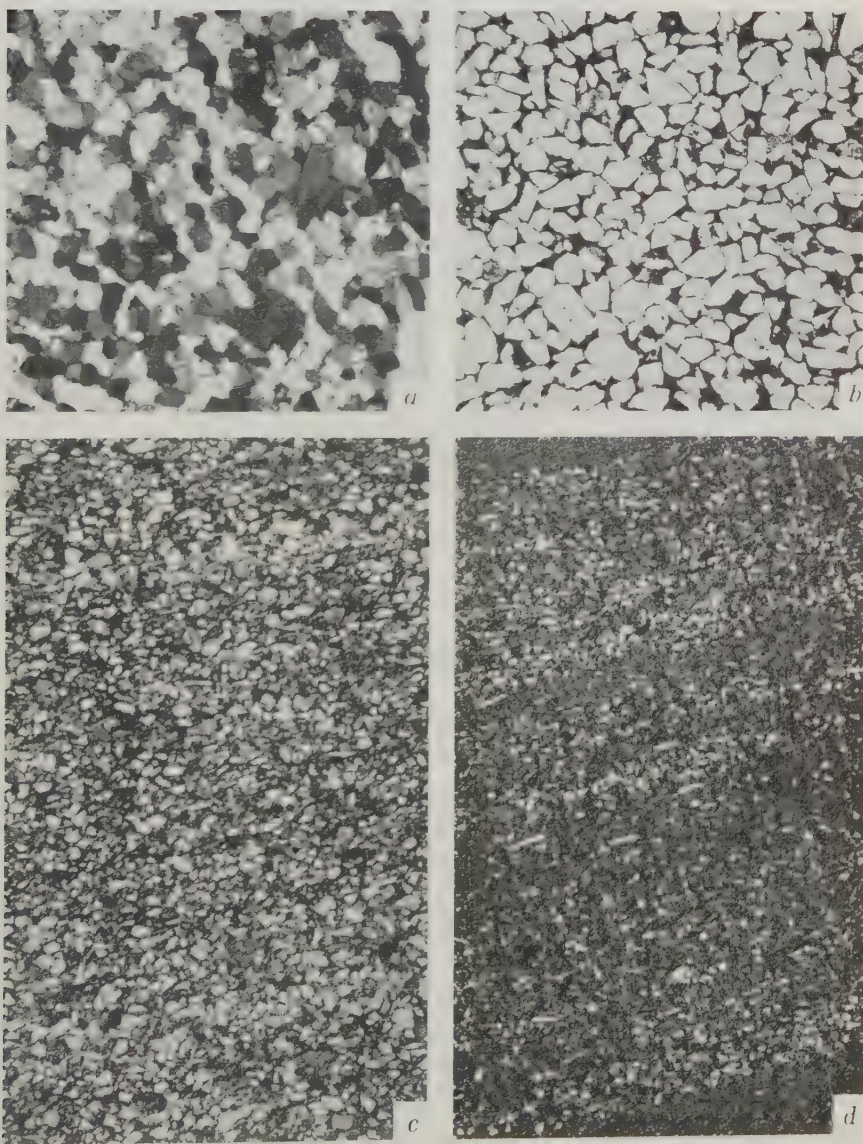


Fig. 3. Thin sections of rocks belonging to the older sandstone series.
a: light-coloured, quartzitic, sandstone (Nic. +), *b*: dark-violet sandstone with limonitic matrix, *c*: arenaceous shale, *d*: Stanges shale. Magnification $18\times$.

a, *b*, *c* from Tananes, *d* from Lille Molvik.

J. F. Stadheim phot.

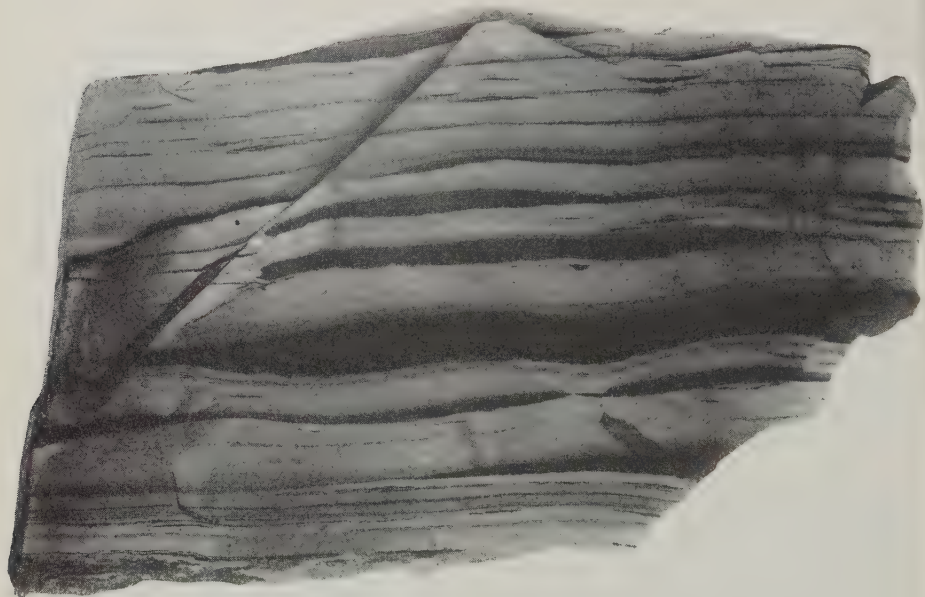


Fig. 4. Stangenes shale, Lille Molvik. The material is somewhat coarser in the dark green bands than in the light green. $\frac{1}{2} \times$.

L. Monsen phot.

The Stangenes shale, so named because it is very conspicuous at Stangenes north of the mouth of the Tana River, presents a more uniform rock, both according to character of the sediments and to grain size. Colours are green or greyish green, with some red bands. Thin layers of pyrites, about 1 mm in thickness, are sometimes seen. The rock has some slaty cleavage at an angle to the bedding planes. The constituents are quartz, biotite and muscovite in a matrix of greenish chlorite; as accessory, zircon appears. The material is of silt grade, the grains being max. 0.1 mm in diameter.

The dark violet sandstone (in the zone 1 at Tananes) is of particular interest. A thin section shows chiefly quartz; accessory, appear plagioclase and microcline. Rounded grains, diameter 0.15 mm to 0.3 mm. Matrix limonitic, reddish, nearly opaque.

In 1931 small layers of bog iron ore containing manganese were discovered in Tarmtjorddal, they were investigated by C. W. Carstens (1933). In the neighbourhood, beds of the dark violet sandstone

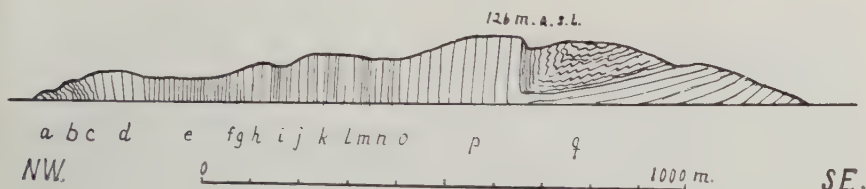


Fig. 5.

occur. A chemical analysis of this gives, according to Carstens, the following result:

SiO_2 79.20%, Fe 12.42%, Mn 0.36%, P 0.032%, S 0.10%.

The limonitic matrix is accordingly manganeseous, and Carstens supposes that this sandstone has yielded the material for the bog ore.

Ripple marks and mudcracks occur in all parts of the series.

In order to solve the question whether the tillite-bearing series is resting unconformably on the older series, I had to get an intimate knowledge of the latter. The section of Tananes, and that of Stangenes—Vagge—Lavvonjargga, are those most favourable for detailed investigations. Very suitable for being used as index zones are the following:

The Vagge quartzite

- q » Vagge shale
- l » dark violet sandstone beds
- e » Stangenes shale
- d » conglomerate layers.

1. The Section of Tananes.

The visible part of the series is about 900 m thick. The series forms a large syncline; NE of the synclinal axis the beds are approximately vertical, in part, somewhat inverted. The thicknesses have been measured by tape-line.

On the north-western part of the promontory, the dip is rather irregular, the thicknesses of the zones b, c, and d, could not be exactly measured.

a. The lowermost zone, on the waterside. Arenaceous shale, micaceous. Small concretions of pyrites.

b. 15 m? Quartzitic sandstone, with violet and brown points.



Fig. 6. About 200 m of the series of Tananes, seen from SW.
(From left, zones h, i, j, k).

c. 20 m? Arenaceous shale. In the upper part occur beds of some peculiar conglomerate. The beds are about 10 cm in thickness. The fragments consist of dark-coloured fine-grained sandstone and of shale. The size of the fragments varies up to about 5 cm, the shape is flat but without sharp edges.

d. 100 m? Quartzitic sandstone. In the lowermost part, about 20 m, the sandstones are brown-pointed, and contain conglomerate layers. The pebbles range up to walnut size, most of them are subangular. Main constituent quartz, subordinate, felspar-fragments, of sizes up to a pea. A thin section of the ground mass shows quartz, microcline and microcline-perthite, plagioclase, muscovite, and pyrites. The minerals are fresh.

e. 185 m. Siltstone. ("The Stangenes shale.")

f. 10 m. Quartzitic sandstone.

g. 10 m. Arenaceous shale.

h. 50 m. Quartzitic sandstone.

i. 35 m. Arenaceous shale.

j. 46 m. Thick beds of quartzitic sandstones alternating with slaty sandstones.

k. 62 m. Arenaceous shale and slaty sandstones with some beds of larger thickness.

l. 38 m. Character of sediments and thickness of beds varying. Conspicuous are beds of dark violet, limonitic sandstone. In connec-

tion with these, grey sandstones with violet points occur. Further, grey, quartzitic sandstones and arenaceous shales.

m. 20 m. Arenaceous shale, with in the middle a bed of sandstone, thickness 0.5 m.

n. 22 m. Alternating beds of violet-brown quartzitic sandstone, reddish siltstone, grey quartzitic sandstone, grey siltstone. The siltstones are easily eroded, the sandstone beds are left, standing as ribs.

o. 100 m. Light-coloured, slightly reddish, quartzitic sandstone. Thicknesses of beds vary, slaty beds intervene, especially in the lower part.

p. 200 m. Light-coloured, slightly reddish, quartzitic sandstone in relatively thick beds.

q. The youngest zone on Tananes consists of dark-coloured slaty sandstones and arenaceous shales. Thicknesses of beds range from some millimetres to 15 cm. The beds are crumbled, except near the basement. Thickness of the zone cannot be measured. ("The Vagge shale.")

2. *Stangenes—Vagge—Lavvonjargga.*

From Tananes the same sequence is seen in the steep slopes to the NE. The distance is about 4 km, but even at this distance the zones may be pointed out roughly. The folding axes dip slightly towards NE, the Vagge shale is seen at Vagge as a well-marked intercalation in light-coloured sandstone, the shale being overlaid by a thick-bedded, pure white, quartzitic sandstone, "the Vagge quart-



Fig. 7. Shale and thin-bedded sandstone.
Tananes, zones b.

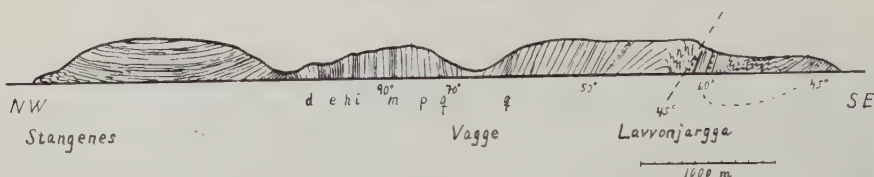


Fig. 8.

zite." The thickness of the Vagge shale is about 80 m, the Vagge quartzite, about 150 m.

In addition to the pure white colour, the Vagge quartzite differs from the reddish sandstone in having coarser and more unequal grains. Quartz is the only constituent, the grains are rounded, grain diameters range from 0.3 mm to 0.7 mm.

At Vagge I measured the strata by pacing. I then found the main features to be in congruity, but a parallellisation between the very beds or small groups of them is difficult, due partly to the absence of distinct divisions between the zones, it being a matter of judgment where to draw the limit between an arenaceous shale and a slaty sandstone. But there are certainly also variations in the sediments from Tananes to Vagge. Such a variation has been pointed out in zone m:

On Tananes: 20 m arenaceous shale, with in the middle a bed of sandstone, thickness 0.5 m.

West of Vagge:

(At top) 10 m arenaceous shale.

0.1 m dark-coloured conglomerate.

1 m dark-coloured shale.

10 m arenaceous shale.

The conglomerate consists of shale fragments, these are not likely to have been transported any distance of importance.

3. *The Eastern Side of the Tanafjord from Stangenes to Grasdalen.*

The older sandstone series make up the steep mountain slopes of the eastern side of the Tanafjord. An especially distinct section is seen in the northern slope of the valley of Lille Molvik. The strike of the strata is N 40° E, the dip is 30° towards NW. The different zones are easily recognizable, thus I found the quartz

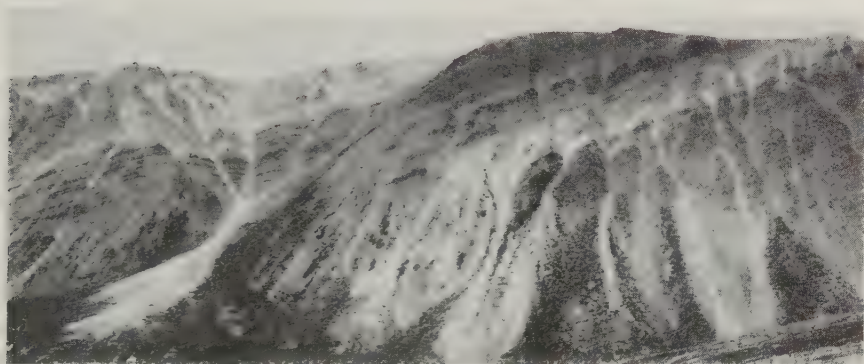


Fig. 9. The older sandstone series north of the Lille Molvik valley.
The mountain side is about 400 m high.

conglomerate (d) in the ridge between the two rivers. On the photograph (Fig. 9), the Stangenes slate is seen to the right, and the light reddish sandstone (p) on the top to the left. The thickness of the strata visible on the photograph is about 700 m.

About 2 km south of Lille Molvik the continuity is to some extent broken by tectonical disturbances.

In the little valley about 3 km north of Lille Molvik we find over the Vagge quartzite a zone of shale containing dolomitic beds. The colours of the shales are in part dark grey, in part red violent with green bands. Some beds contain intraformational conglomerate with shale fragments. The rocks also occur at Grasdalen, a locality about 4 km further north (Holtedahl, 1918, p. 179). The shales are there overlaid by the tillite-bearing sandstone series. Noticeable are the intraformational dolomite conglomerates, closely resembling those in the Porsanger dolomite.

I estimate the thickness of the dolomite and shale zone at about 50 m, but it cannot be accurately measured owing to the debris at the bottom of the valley.

B. The Unconformity.

Of considerable interest is the existence of an unconformity between the tillite-bearing series and the older sandstone series. The angle between the two series cannot be directly observed, being only 1° or 2° ; the lower tillite is, however, resting on various zones

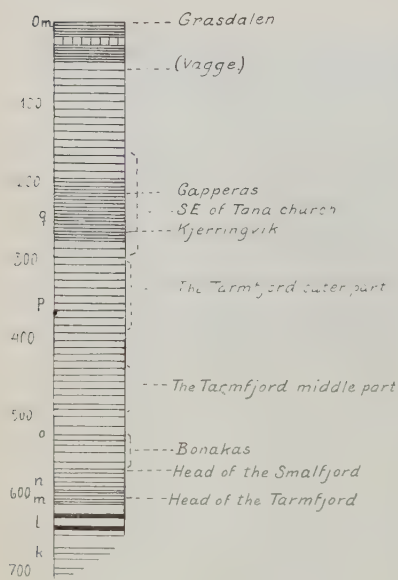


Fig. 10. Diagram showing the varying basement of the lower tillite. (At Vagge the tillite-bearing series is absent, but the now-present top of the older series is indicated.)

of the older series, and thus the angle has been indirectly measured. On the Varangerfjord, the corresponding unconformity has previously been stated by O. Holtedahl (1918, p. 166, in English summary, p. 309).

The basement of the lower tillite at different localities appears from the diagram. The difference between Vagge and Gapperas (the peak outermost on the peninsula west of the Smalfjord) is striking. At Gapperas, the, at least, 150 m thick Vagge quartzite is lacking and also about 30 m of the Vagge shale, which is here only about 50 m thick. The distance between the localities is 10 km, the angle of the unconformity is 1° .

At Kjerringvik, 2 km farther up the fjord, the Vagge shale is only 5 à 7 m thick. About the same angle.

Farther up the fjord the tillite rests on still older beds. The Vagge shale disappears, as does gradually the upper part of the light-reddish sandstone. At

the head of the fjord, the sandstone below the tillite contains intercalations of dark-coloured shales.

On the west side of the outermost part of the Tarmfjord the tillite rests on the light-coloured sandstone, not, however, on its uppermost thick-bedded part. At the head of the fjord, zones of dark-coloured shale occur only 20 à 30 m below the tillite, and a little farther downwards, the conspicuous beds of dark violet limonitic sandstone appear. At least 200 m of the series have disappeared in the course of about 5 km; the angle is here more than 2° .

One may to some extent determine the direction of the largest angle of unconformity. Lines drawn between the localities where the tillite has the same basement, have the direction N 50° à 60° W--S 50° à 60° E. Thus the direction of the largest unconformity is towards N 30° à 40° E.



Fig. 11. The Capperas mountain, seen from SW. The lower tillite bed forms the slope to the left, the bed rests upon the Vagge shale, which again lies upon light-coloured sandstone.

An indication that the unconformity is due to erosion and has not been caused by changes of facies or original dying out of beds, is the occurrence at Gapperas of a breccia which forms the transition rock between the Vagge shale and the tillite. The breccia is about 1 m in thickness. Angular fragments of dark green arenaceous shale are lying irregularly in a matrix of a shade of lighter green colour. The size of the fragments varies from 10 cm and downwards, the mineral constituents are quartz (diameter about 0.05 mm), muscovite, green chlorite, iron ore, and a little biotite. The lamination in the shale fragments is due to the varying amount of chlorite relative to quartz. The matrix has the same constituent as the fragments, but the amount of mica and chlorite relative to quartz is larger.

The material forming the breccia is obviously derived from the rocks below, belonging to the Vagge shale. The fragments are identical with the arenaceous beds, whilst the more clayey beds have afforded the material for the matrix. Furthermore, transitions from regular beds to breccia have been observed.

The transition from breccia to tillite is also not distinct, small parts of the breccia rock and fragments of the shale have been found in the lowermost part of the tillite. And, in the breccia, some straggling rock fragments of foreign origin occur.

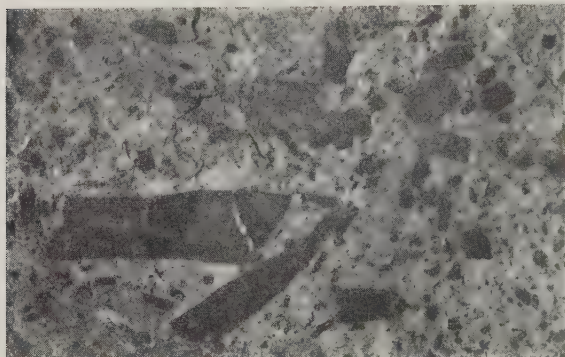


Fig. 12. Breccia below the lower tillite at Gapperas. $1/2\times$.
L. Monsen phot.

Obviously a glacier, possibly the base of floating icebergs, have in the remote glacial period eroded the Vagge shale. Most probably the grinding has taken place in shallow waters.

Crushing phenomena of another origin are frequently found at the plane of junction between

the solid tillite layer and flexible shales, the crushing being due to the different power of resistance towards folding. Such breccias are schistose and are traversed by joints or by veins of quartz or calcite. The breccia rock at Gapperas, however, has no schistosity and is entirely consolidated. Further, the occurrence of foreign rock fragments (granite) in the breccia can only be explained by supposing the ancient glacier (or floating icebergs) to have been the crushing agent.

The breccia zone has been observed at several places near Gapperas, investigations may most favourably be carried out at the eastern side of the hill NNE of the top of Gapperas.

Glacial striae on the substratum of the tillite have not been found in the Tana district.

C. The Tillite-bearing Series on the Tanafjord.

The tillites occur as two extensive layers, separated by a stage of brown and red sandstones and red and green shales. Above the upper tillite comes a stage consisting of beds of light-coloured sandstone and dark-coloured arenaceous shale alternately. This stage is overlaid by a slaty mudstone, the colours of which are in the lowermost part red, in the upper, larger part, bluish green.

These rocks have a rather wide distribution in the Tana district, and a number of localities will be described, but general description

of the stages is first needed. The rocks higher up in the sequence will be described in connection with the description of certain localities on the peninsula between the Tanafjord and the Langfjord.

The thickness of the tillite beds and of the intervening shale-sandstone zone is variable, evidently original; the variation will be discussed in the summary.

1. *The Lower Tillite.*

The rock consists chiefly of material of silt and clay grade, which forms a matrix in which rock fragments of all sizes are dispersed. At first sight the rock appears most often as a thoroughly unassorted one; on closer investigation, however, the material is found in a number of cases to be somewhat assorted. This stratification may be of different kinds:

1. Rather large parts of the rock have some coarse assortment. Irregular layers — or lenses — of gravel, consisting in itself of fragments of varying sizes, alternate with fine material. It resembles glacialfluvial deposits. This kind of stratification is often observed on the peninsulas between the Smalfjord and the Vestertanafjord.

2. Some distinctly assorted horizons occur, the tillite being otherwise unassorted. The layers may be up to 30 cm in thickness. Usually, only the finest material is assorted, whilst pebbles and larger blocks are irregularly dispersed.

3. Even when the rock appears unassorted some traces of stratification may be observed, lines of very fine-grained material alternating with lines of some coarser grain. The lines are not entirely parallel and may die out after a little distance.

4. Also in cases where no stratification is apparent, a microscopical one may occur, the flakes of mica and also the elongate fragments of other minerals being subparallelly arranged.

During the period of folding, the tillite has received a secondary schistosity, which more or less disturbs the traces of stratification.

The erratics in the tillite may be of all sizes up to 2 m in diameter, boulders larger than 0.5 m in diameter, however, do not frequently occur. The shapes are usually irregular, but the edges are somewhat rounded. Also entirely angular erratics may occur, especially near the southern border of the sedimentary rocks.

Some boulders with glacial striae have been found by H. Reusch (1891) in the (upper) tillite at Bergeby in the Varanger district and by O. Holtedahl (1918) in the Alta district. In the Tana district, not a single stone with glacial striae has been found. I have, however, made no special search for striated boulders.

Dolomite is the rock most frequently occurring among the erratics in the lower tillite. On the peninsulas between the Smalfjord and the Vestertanafjord dolomite, in particular, dominates. The weathered surface of the dolomite has a brownish yellow colour, the fresh fracture is light greyish. Usually the rock shows no structure; there have been found, however, fragments of oolitic rock, of dolomite breccia, and fragments with stromatolites. Such rocks also occur in silicified state.

Next to dolomite, Pre-Cambrian crystalline rocks are most common. Near the southern border of the sediments these rocks prevail. The rocks are granites, granodiorites, quartz diorites, gneiss-granites, gneisses, and diabases. A petrographic description will be given in connection with the problem of the source of the tillite material (p. 124). Erratics of quartzitic sandstone have also rather frequently been found; none of them was above the size of a man's head.

The colours of the lower tillite are greenish-grey, brownish-yellow, or red-brown. The greenish colour is due to chloritic material in the matrix, most part of the chlorite is evidently authigenic. With increasing amount of dolomite the colour of the surface grows grey and gradually brownish-yellow, dolomite being the predominating constituent both of matrix and erratics. The fresh fracture of the dolomitic tillite has a light grey colour.

The red-brown colour, typical of the tillites near the southern border of the sediments, is due to a fine-grained opaque mass dispersed between the fragments, the mass looking red by reflected light.

The matrix always constitutes a larger part of the rock than do the erratics. The amount of erratics may be so small that such are found only after some search; the rock is then to be termed coarsely arenaceous mudstone (e. g. some places between the Smalfjord and Bonakas). However, at least, small erratics used to occur.

Thin sections. As examples, three specimens are described:

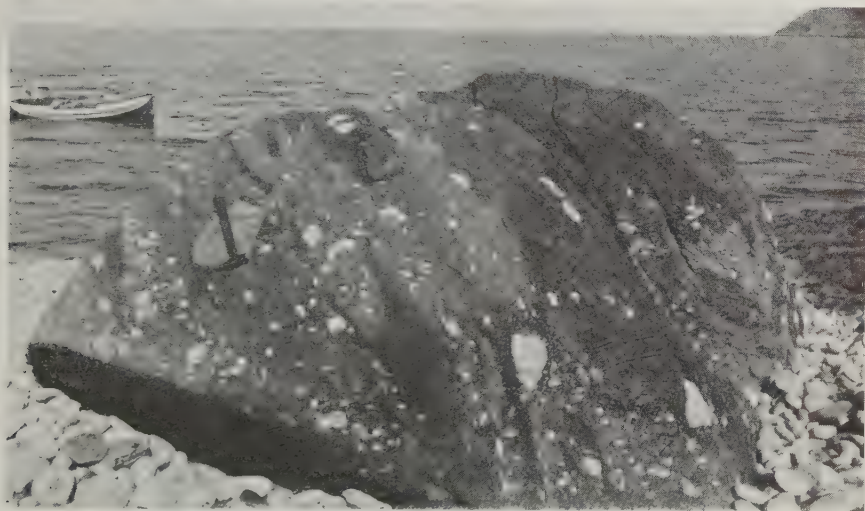


Fig. 13. Dolomitic tillite with coarse stratification. Local block, from the lower tillite, loc. No. 2, Tarmfjord.

1. Greyish-green tillite poor in erratics. Locality: West side of the upper end of the Smalfjord (loc. No. 8).

Lower part of the tillite layer. Megascopic no stratification. Schistosity slightly developed. With the microscope: Quartz in angular grains, fresh plagioclase, some microcline, muscovite, biotite, some grains or other of tourmaline, a little chlorite and carbonate, in a matrix which chiefly consists of minute grains of the same constituents. The mica flakes are subparallelly arranged, at an oblique angle to the planes of schistosity.

2. Dolomitic tillite, brownish-yellow in colour. Locality: (No. 2) 4 km NE of Torhop. The coarser material of the specimen is unassorted, but very small elongate fragments are subparallelly arranged. The rock has no schistosity.

With the microscope: Fragments of a fine-grained carbonate rock, fragments of carbonate, quartz, muscovite, some iron ore, and accessory grains of microcline and zircon. The quartz grains are sharply angular, the sizes range from 0.03 mm to 0.1 mm. The microstratification appears clearly.

3. Red-brown tillite. Locality: Čikkojok. Megascopic no assortment, and no schistosity. Microphot. Fig. 14.

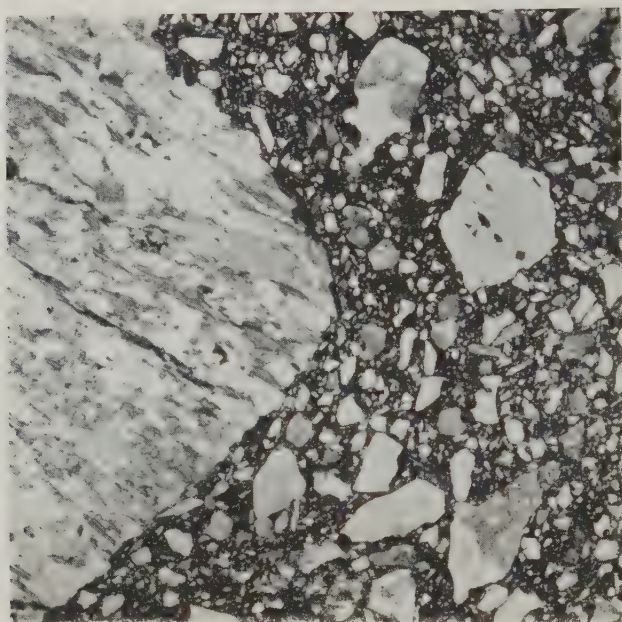


Fig. 14. Thin section of the lower tillite, Čikkojok.
Fragments of gneiss and quartz. Colour of the matrix red-brown.
Nic. $\pm$. $18\times$. J. F. Stadheim phot.

With the microscope: Sharply angular fragments of quartz, acid plagioclase, biotite, muscovite, garnet, chlorite, magnetite, and of gneiss consisting of the same minerals. The fragments are numerous, and of all sizes, the red-brown actual matrix of clay grade is present in comparatively small quantity. No stratification at all.

2. *The Red and Brown Sandstone and Red and Green Shale.*

The very contact between the lower tillite and this stage has not been frequently observed, the shales being eroded more easily than the tillite and the contact therefore being covered with loose deposits. The very contact can be seen on the shore about 3 km NE of Torhop (Tarmfjord), the transition there appears to be continuous, the amount of erratics in the uppermost part of the tillite gradually disappearing, the material at the same time growing regularly assorted. The lowermost shales are green in colour; slightly above, however,

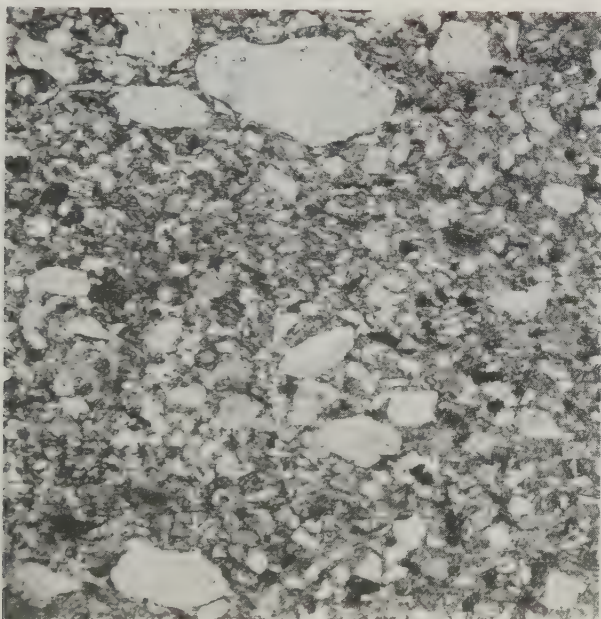


Fig. 15. Thin section of sandstone, from the stage between the tillites. Seida.
The minerals are chiefly quartz, felspar, garnet, and magnetite.
Nic. $\pm$. 18 $\times$. J. F. Stadheim phot.

the red colours predominate. Lowest, there are a few metres of red shale which has a conspicuously vivid colour; sandstones are absent. The difference in colour is due to contents of dolomitic material.

The bright red colour is characteristic of the basal zone of this stage all over the Tana district. Dolomite may in some layers be the predominant constituent and the rock has a yellow colour. In this case, quartz grains and lines of red-brown clayey material form impurities only.

In the larger part of the stage, sandstones and shales alternate. The red shale contains green layers appearing on the planes of schistosity as green bands. The lamination may remind one somewhat of "varves", although the banding is too irregular to give a definite impression of varves. Ripple marks occur.

The development of this stage in the environment of the upper end of the Tanafjord differs from that in the areas near the southern border of the sediments. On the Tanafjord the thicknesses of the sandstone beds may be 10—20—30 cm, sometimes more, but in

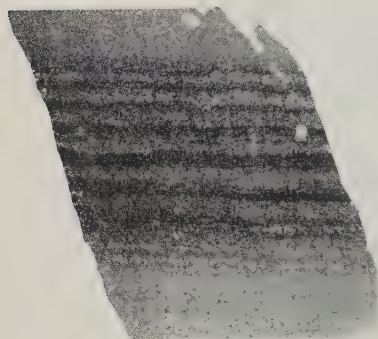


Fig. 16. Thin section of red and green shale, from the head of the Smalfjord. See text, p. 84. Magnification $5\times$.

L. Monsen phot.

few cases above 50 cm. The quantity of sandstone is equal, or nearly so, to that of the shale; as to the grain size, the material ranges from clay to medium sand. In the southern areas, however, the sandstone largely exceeds the shale in quantity. The average thickness of the beds is increased, beds more than 1 m in thickness are common. The maximum size of the grains is also increased, so that in a number of cases, the sandstone must be described as "very coarse", the grains being up to 3 mm in diameter. Always, however, there are beds of shale and of sandstone of medium grade.

The main constituents of the sandstones are quartz, acid plagioclase, garnet, and magnetite; zircon and rutile appear in smaller quantity, and some biotite, chlorite, and muscovite use to occur.

In some beds the quantity of garnet is very large.

From sandstone to shale the quantity of mica and chlorite increases, and the heavy minerals and feldspar disappear. Thin sections of the red shales show small grains of quartz, biotite and muscovite in a fibrous, very fine-grained mass. The biotite is brownish-green, as the muscovite more or less changed into green chlorite. To a large extent, the muscovite is probably authigenic.

In the green shale the fibrous matrix seems to consist chiefly of muscovite and chlorite, the refraction being rather high, the interference colours being partly vivid, partly low and anomalous. Some grains of authigenic pyrites may occur.

In the red shale chlorite and muscovite appear in somewhat smaller quantity. The red colour is due to finely-divided particles of ferruginous matter.

In Fig. 16 a microphoto. of banded red and green shale is seen. The thin section has been cut perpendicularly to both lamination and schistosity. The lamination seen is due to alternating lines of somewhat lighter and darker red colour. The distance between two uniform lines is about 0.5 mm. On large magnification, the lamination also appears with the subparallel orientation of the mica. The planes



Fig. 17. Slate quarry at Alteberget.

of schistosity cut off the larger flakes of mica into parallelograms. The distance between two primitive planes of schistosity is about 0.02 mm. Different parts of one mica flake may be relatively displaced or they may have collapsed on account of compression. Very small flakes of mica have developed along the planes of schistosity, and in the red part of the shale, the dark ferruginous substance has been concentrated along the planes.

Taken as a whole, the bands of differing colour and the lamination are parallel; but bands of more irregular, in part lenticular, shape also occur. One gets an impression that the variation of the colours is secondary, even if primarily induced. See Fig. 19.

At Alteberget in Vestertana, the lamination of the shales is coincidental with the schistosity; roofing-slates are here quarried.

3. *The Upper Tillite.*

The transition from the shale-sandstone stage to the upper tillite is continuous, wherever it has not been destroyed by tectonical disturbances. The colour of the tillite is greyish-green, except near the southern border of the sediments, where red-brown colour occurs, as in the case of the lower tillite. The boulders in the upper tillite

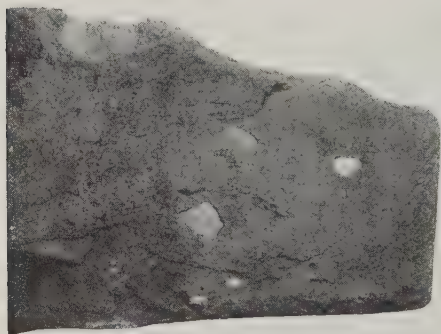


Fig. 18. Grey-green tillite, with three dolomite pebbles and, uppermost, a gneiss pebble. The upper tillite, Stappogiedde. $1,4 \times$.

L. Monsen phot.

chiefly consist of Pre-Cambrian crystalline rocks, dolomite rocks being in the second rank. In the upper tillite, small fragments of green or red shale occur in a number of cases. The size of the fragments is up to 1 cm in length; the fragments are generally pressed flat in accordance to the schistosity of the tillite. The colour of the tillite agrees with that of the shale fragments, one single case excepted, where one fragment of green shale occurs together

with red fragments in red brown tillite. In the lower tillite, I have only at one place observed a general occurrence of shale fragments, viz., at Grasdalen, where fragments of dark shale are present. It must be remembered that the tillite there rests on the zone of dolomite and dark shale.

4. *The Dark-coloured Shale and Light-coloured Sandstone.*

The upper tillite shades upwards into a dark arenaceous shale, the amount and the size of the erratics decreasing and, at last, disappearing, the fine material growing regularly stratified. Somewhat higher, massive beds of sandstone occur, alternating with the shales. The sandstone beds may be more than 1 m in thickness, and the material may be very coarse, the grains being up to the size of a pea. The grains are most often angular; besides quartz, feldspars are frequently present, the plagioclase is fresh. The colour of the sandstone is most often white, locally dark beds occur. The shales are dark-coloured, arenaceous, micaceous; they split in thin sheets along the bedding planes. The very sheets may be rather arenaceous, but separated by a layer of clay material.

The sudden alternations between thin-splitting shales and massive beds of coarse material, indicate rapid variations in the conditions of depositing. Ripple marks are frequently observed.

The thickness of the stage varies somewhat, generally, it is between 20 m and 40 m. Any regularity in the variation has not been found.

5. *The Red-violet and the Bluish-green Shale.*

Gradually the conditions of deposition seem to stabilize, the next 100 à 150 m consist of a rather homogeneous shale rock. One relapse occurs: there is in the lowermost part a bed of sandstone, about 1 m thick, of the same kind as described above.

In the lowermost part, about 25 m, the shale is of red-violet colour, with green bands, and is quite like the most fine-grained shale in the stage between the tillites. The upper, larger part, has a purely bluish-green colour. The rocks have almost always a slaty cleavage, which in few cases is coincidental with the lamination. Any bedding is not generally seen; the lamination appears on the planes of schistosity as lines of slightly differing lustre, the somewhat coarser material reflecting the light more diffusely, and often also being a shade darker in colour than the finest material. The lines may be of a most varied breadth, from a fraction of a millimeter to some centimeters.

The lines are suggestive of varves, but they are perhaps too irregular.

In the red-violet shale, the lamination is also indicated by the green bands; however, these bands are, as in the shale between the tillites, not always quite regular.

Thin section of bluish-green shale: In a greenish, very fine-grained mass, one may distinguish grains of quartz and of colourless mica, in part changed into green chlorite. In the more coarse-grained layers the quartz may be up to 0.05 mm in diameter.

The colour of the red-violet shale is due to red-coloured dust-like particles.

The eastern development of the stage seems to differ from that of the north-western. In the former (Maskejavrre — Leirpollen) the

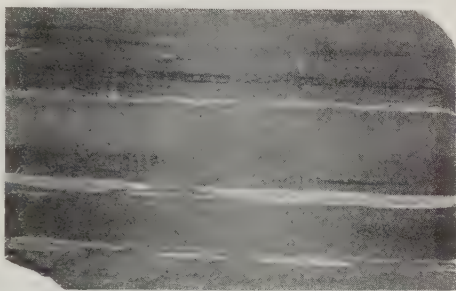


Fig. 19. Red-violet shale, with light-greenish, somewhat irregular, bands. Between Grasdalen and Trollfjord. $\frac{1}{4} \times$.

L. Monsen phot.

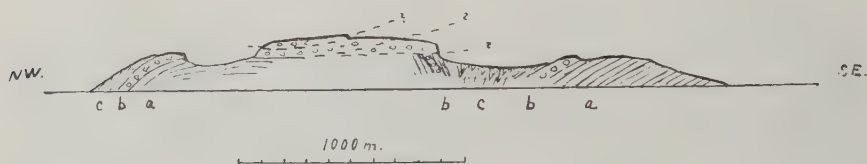


Fig. 20. *a*: sandstone of the older series, *b*: the lower tillite, *c*: red and brown sandstone and shale, - - - thrust plane.

thickness seems to be somewhat larger than in the north-western (Vestertana, and westwards); however, no exact measurements have been made. Further, in the eastern district two strokes of rather compact beds are noted; these beds of relatively arenaceous material stand out a little on the mountain sides.

6. *Description of Some Localities on or near the Tanafjord.*

The peninsula between the Smalfjord and the Tarmfjord. An anticline forms the ridge of the peninsula and a syncline forms the valley east of it (section, Fig. 20). The tillite of the anticline has in part been thrust above the red and brown sandstone and shale of the valley. The direction of the folding axes is N 45 E.

Outermost on the peninsula, the lower tillite rests on Vagge shale, which disappears towards the SW, where the tillite rests on light reddish quartzitic sandstone. Along the Smalfjord the quartzite and the tillite have a regular dip towards NW. In the outer part of the north-western side of the peninsula, the quartzite lies fairly flat, but south of Torhop the strike and dip of the rocks are very irregular, and farther south, at Öokkales (loc. No. 7) parts of the quartzite have been thrust over the tillite.

On the outer part of the peninsula, the lower half of the tillite layer is dolomitic, and of brownish-yellow colour, whilst the upper half is greyish-green. The border plane is rather distinct. On account of overthrusts this group — the brownish-yellow tillite and the greyish-green tillite — may occur twice, in cases thrice, one over the other; the thrust planes are more or less perceptible.

In the dolomitic part of the tillite, both the erratics and the matrix consist chiefly, in some cases, exclusively, of dolomite and silicified dolomite.

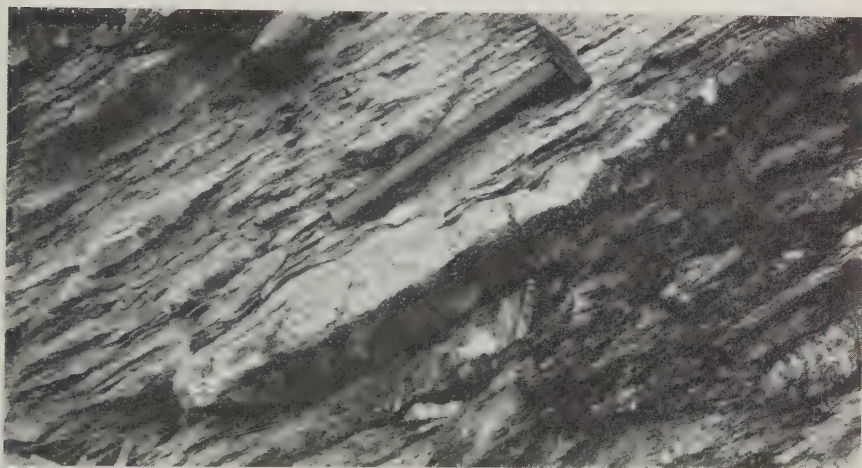


Fig. 21. Tillite with strongly deformed dolomite boulders. The dip of the schistosity is NW. Between loc. Nos. 4 and 5.

Boulders of gneisses, granitic rocks, diabases and sandstones have been observed, but in few cases. The size of the boulders may be up to one metre in diameter, but are seldom above half a metre. A coarse assortment is often seen. In the greyish green type, the amount of boulders is far smaller. The amount of dolomite boulders has diminished, whilst that of the other rocks is about as in the dolomitic tillite. The maximum size of the boulders is smaller in the greyish green tillite.

The thickness of the dolomitic part diminishes towards the south.

Loc. No. 1. A portion of light-coloured quartzite, evidently been placed there by tectonical movements, occurs in the tillite.

Loc. No. 2. The autochthonic tillite is 20 m à 25 m in thickness; the dolomitic tillite constitutes about the half.

Loc. No. 3. Portions of red shale may be seen between the autochthonic tillite and the overthrust one. At the base of the overthrust tillite, portions of the light-reddish quartzitic sandstones and of some dark basal layers of the tillite happen to occur.

Between loc. No. 2 and loc. No. 4, on the shore, the tillite is normally overlaid by red shale. The shale extends about 2 km towards the SW, but disappears just south of the road, being squeezed out by an overthrust tillite mass.

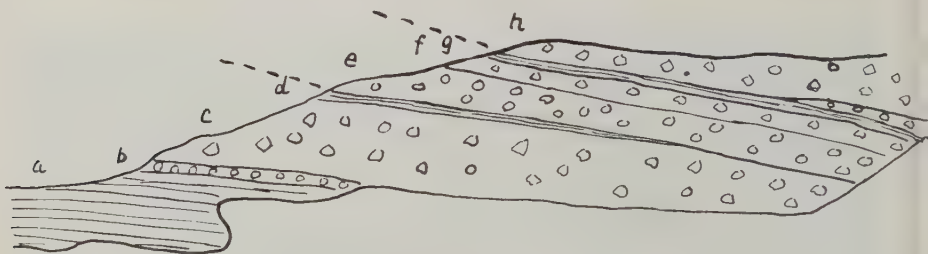


Fig. 22. Loc. No. 6, (see photo. Fig. 23). a light-coloured sandstone, b 1 m dolomitic tillite, c 15 à 20 m greyish-green tillite, d dolomitic red shale, e 7 à 8 m dolomitic tillite, f 3 à 4 m green tillite, g 2 m dolomitic red shale, h dolomitic tillite. Thrust planes between d and e, and between g and h.

Loc. No. 4. A crag of tillite and light coloured sandstone lies on red shale.

Loc. No. 5. West of Bogejavrr, contact is seen between the autochthonic tillite and its substrata, light-reddish, quartzitic sandstone. The strata dip towards SE. The basal part of the tillite consists of a greyish green, coarse-grained, arenaceous rock, containing a few erratics. Thickness of this part is about 1 m. Above this comes about 5 m dolomitic tillite, coarsely assorted, and thereon greyish green tillite.

Loc. No. 6. Here the thickness of the dolomitic tillite is only about 1 m, it has a coarse assortment. I have not observed the direct contact with the substratum. On the dolomitic bed rests a greyish arenaceous rock with few erratics, and thereupon greyish green tillite 15 à 20 m in thickness. At the eastern side of the anticline, the dip is nearly vertically, the tillite is overlaid by the vividly red-coloured beds in the lowermost part of the red brown shale-sandstone zone. But at the west side of the anticline only a thin zone of red shale is seen, and above it, again tillite. This shale is sheared, it thins out and disappears towards the west so that the overthrust tillite and the autochthonic come into contact. Also the lowermost part of the overthrust tillite is somewhat sheared and the dolomite boulders flattened. These are intersected by two systems of joints filled with quartz. The quartz planes do not intersect the ground mass of the tillite; but they must have been formed in

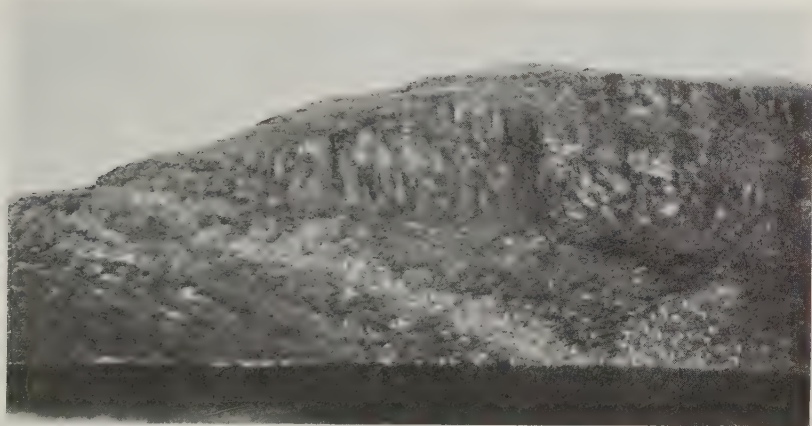


Fig. 23. Loc. No. 6. Seen from NE. For explanation see Fig. 22.

connection with the shearing, as the joints are missing where the tillite has not been exposed to shearing. Further, the systems of joints in neighbouring boulders have about the same orientation.

As seen from the section (Fig. 22) another thrust plane (probably) occurs higher up.

Loc. No. 7. In addition to the thrust sandstone, some portion of the tillite is probably allochthonic. Just east of the thrust sandstone masses, there occur in the tillite portions of red dolomitic shale, probably belonging to the zone above the tillite, and thus, in this case, separating allochthonic tillite from autochthonic. Perhaps, however, they may be layers in the tillite, as can be seen west of the Tarmfjord.

The head of the Smalfjord, and eastward to Bonakas.

Loc. No. 8. In the "132" m hill the tillite rests on flat-lying beds of light-coloured sandstone. Here the tillite has a basal zone, about 8 m in thickness, of laminated siltstone, with a steep, slaty cleavage. The colours of the slates are mostly red, with green bands, but also green with darker green bands. The actual contact between siltstone and the underlying sandstone cannot be observed. The transition from siltstone to tillite is continuous, the stratification disappearing and small erratics occurring. The lamination and the border plane are conformable, and the material is in both cases of the same kind, but coarser above the border plane. Quartz is the main constituent of the siltstone; further, microcline, sericitized

plagioclase, muscovite, carbonate, a little iron ore and green chlorite occur. The chlorite seems in part to be developed from brown biotite.

The whole of the tillite is of the greyish-green type, poor in erratics. The thickness is about 45 m, the basal layers excepted. On the steep side to the west, a distinct line in the tillite, about 15 m from the top, can be seen. It is a stratigraphical border; the tillite above is more greyish in colour than the green tillite below; further, it contains more erratics and is harder than the rock below. At the border plane, I have observed a boulder of flint (of size about 30 cm in diameter), adhering to both parts of the tillite.

The thickness of the tillite is worth noting. It is larger than farther north, despite the fact that the dolomitic tillite is absent.

Between the head of the Smalfjord and the Tana River the tillite is everywhere green or greyish-green, and contains few erratics, at some places almost none. Just east of the Smalfjord the tillite has the basal zone of stratified siltstone, farther east, the tillite material lies on the light-coloured sandstone direct.

Along the Bonakas River, the upper tillite stands as a steep wall. It keeps this steep position more towards the SW to eastern Bjørnevann. South of Bjørnevann, ridges of the upper tillite and of red-brown shale and sandstone occur alternately. 9 km south of the head of the Smalfjord, a crag of the older sandstone series projects, the anticlinal axis doming. West thereof, a thin zone of the lower tillite is found, overlaid by red-brown shale and sandstone. As the rock around the crag is to a rather high degree covered with loose deposits and vegetation, no exact measurements of the thickness of the tillite can be made; it seems, however, only to be a few meters, i. e. the thickness seems to be much smaller here than on the Smalfjord.

East of the Tana River. At Rødberget the following sequence can be identified:

Bluish-green shale, the basal part red-violet.

Dark arenaceous shale and light-coloured sandstone.

Upper tillite.

Red-brown shale.

Lower tillite.

Light-coloured quartzitic sandstone.



Fig. 24. Sandstone of the older series resting with thrust contact on the lower tillite. Čokkales (loc. No. 7).

The name Rødberget ("The Red Cliff") is due to the vividly red colour of the slope of *débris*, formed by the disintegration of the zone between the tillites. The slope of Blåberget ("The Blue Cliff") consists of *débris* from the bluish green shale above the upper tillite.

Farther north, the lower tillite is situated at the top of the precipice. The thickness of the tillite is more than 20 m, the tillite is rich in boulders of several kinds of rocks, the size of the boulders being often that of a man's head. No stratification is seen. The colour of the tillite is grey, neither like that of the dolomitic tillite nor the usual greyish-green.

Most southerly, the tillite, as said, rests on light-coloured sandstone. To the north, the Vagge shale intervenes, with increasing thickness. In the latitude of Tana Church it has its whole thickness and is overlaid by Vagge quartzite; however, here the tillite-bearing sandstone series is separated from the older series by a disconformity of tectonical kind.

The tectonical conditions are rather peculiar. The positions of the beds in the valley east of Tana Church appear from the section (Fig. 25, and Fig. 26). The beds of the younger sequence are inverted, the dip being conformable with the thrust plane, about 60° to WNW. Of the lower tillite only remains are found, on the north side of the valley. The thickness of the red-brown shale seems to be smaller than at Rødberget, the stage being probably somewhat squeezed. The

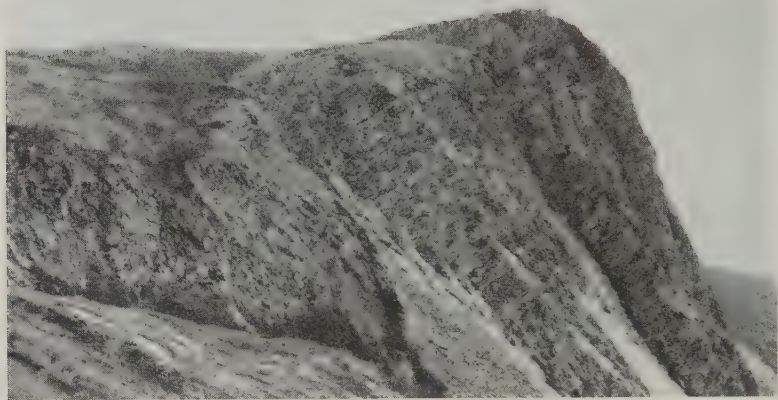


Fig. 25. The little valley on the east side of the Tana River, east of Tana Church. Seen from NE. For explanation see Fig. 26.

vividly red dolomitic beds just above the lower tillite are clearly visible. The upper tillite, the stage of dark arenaceous shale and light-coloured sandstone, the bluish-green shale with the red-violet basal beds, are well exposed farther up the river-cut.

The beds of the older series stand about perpendicular to the beds of the younger one, the dip being about 30° to ESE.

Some distance north of the valley, both of the tillites and the intervening zone are lacking; the older series is found in contact with the bluish-green shale.

The thrust plane at Lavvonjargga (sect. Fig. 8) is perhaps a continuation of that just mentioned. There the lower tillite borders on the older sandstone series, the contact being of tectonical kind. The lower tillite is strongly sheared; any measurement of the thickness is of no use. The stage between the tillites is of about 100 m in thickness (measured by pacing). The beds are inverted, the dip is 60° to NW. The zone here consists nearly exclusively of shale. The upper tillite is about 10 m thick, it is rich in boulders, its colour greyish-green. The stage of dark arenaceous shale and light-coloured sandstone has a thickness of 20 m, the dip is 80° to NW (inverted).

The rocks of the syncline are the bluish-green shale. The pretty red-violet green-banded basal beds are seen quite a distance along the shore. At Lille Leirpollen the underlying strata rise again.

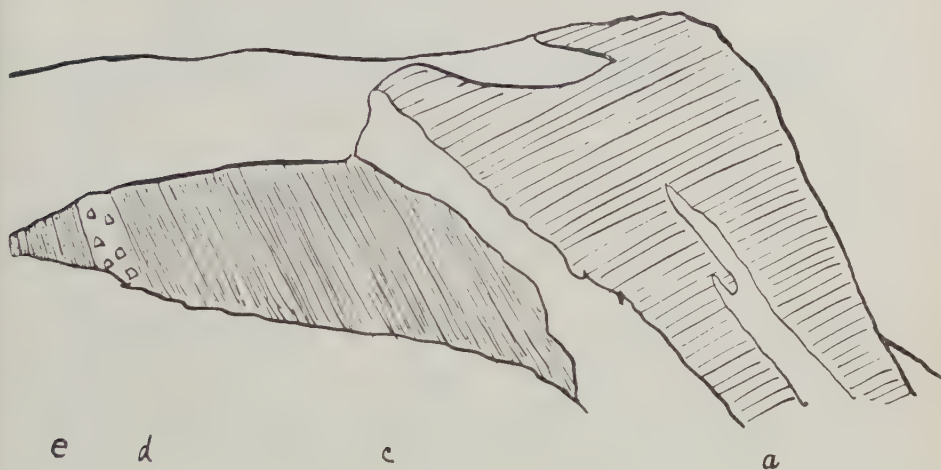


Fig. 26. Loc. like that of Fig. 25.
a sandstone of the older series, c red-brown shale, d the upper tillite,
e dark-coloured shale and light-coloured sandstone.

Leirpollen. West of the outer part of Leirpollen, the upper tillite and its adjacent rocks are exposed. In a little quarry along the road, the underlying green and red shales are found, the border plane against the tillite, and the lamination of the shales are entirely conformable. The tillite is dark greyish-green, it carries erratics of all kinds, but comparatively much of dolomite. The thickness is about 10 m. The overlying zone is at most 20 m in thickness. The sandstones may be of very coarse grain. Some of the beds have a rather dark colour.

East of the uppermost part of Leirpollen some crags of the upper tillite appear at the base of Lammeskallefjellet. At some distance farther north, a white quartzite is exposed, it is the Vagge quartzite, and, nearer the sea, the light-reddish quartzite is found. The stratigraphical distance between the Vagge quartzite and the upper tillite is peculiarly small; consequently the thickness of the zone between the tillites must also be very small. Studies along the little river north of Lammeskallefjellet may perhaps clear up the problem of the thickness of the lower tillite and of the red brown shale. Any tectonical disturbances of importance do not seem to be present.

Grasdalen and Trollfjord (section Fig. 28) are the most northern localities from which the tillites of the Tana district are



Fig. 27. Lammeskallefjellet, east of Leirpollen. a light reddish quartzite, a' Vagge quartzite, d the upper tillite, e dark shale and light-coloured sandstone, f blue-green shale (containing two strokes of harder beds), g red quartzite.

Lowermost a quaternary shore terrace.

known. The younger series here occurs as an isolated portion surrounded by the older sandstone series to the south, east and north.

At Grasdalen (see Holtedahl, 1918, p. 179) the lower tillite rests on a zone consisting of dark shale and of dolomite, which is the uppermost zone known of the older sandstone series. The tillite is rather dark grey, the erratics are small, usually below 10 cm in diameter. Dolomite rocks are most often seen, but also Pre-Cambrian crystalline rocks are found. Small fragments of dark shale occur frequently.

The thickness of the tillite layer is 7 m; some stratification appears in the lowermost and the uppermost portion. The tillite layer dips towards north; it is overlaid by red-brown or green shale. Higher up this stage, beds of greyish-brown colour occur; the thickness of each bed is 10 à 20 cm.

About 1 km north of Grasdalen, south of the little river, brownish-yellow crags of the upper tillite are seen on the hillside. It is, for once, rich in carbonate; both erratics and groundmass effervesce with dilute hydrochloride acid. The thickness is 10 à 15 m (without any pretence to accuracy).

The upper tillite does not occur on the shore on account of tectonical disturbances. The greyish-brown sandstone below, there comes in contact with the stage above the tillite, viz., the dark arenaceous shale and coarse sandstone. This stage is here at least 20 m in thickness.

Farther north, the mountain side is made up by red-violet shale and bluish-green shale. On the promontory, the upper tillite and the adjacent rocks appear. The mountain side south of the Trollfjord consists of the bluish-green shale, a short distance excepted, where a portion of light-coloured sandstone lies with a tectonical contact to the shale.

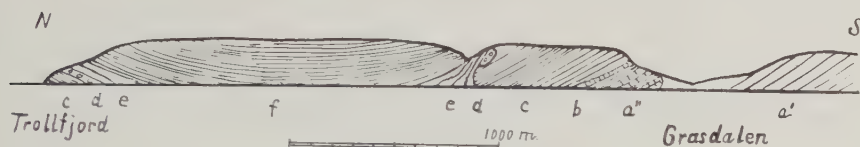


Fig. 28. a' Vagge quartzite, a'' shale and dolomite, b lower tillite, c red-brown and green sandstone and shale, d upper tillite, e dark shale and light sandstone, f red-violet shale and blue-green shale.

South of the head of the Trollfjord, I have observed the whole sequence of rocks from the dolomite-bearing dark shale to the bluish-green shale.

The lower tillite is, as at Grasdalen, dark-coloured and hard; the erratics are most often of dolomite rocks, but granites, gneisses and sandstones are also observed. Of the upper tillite only some crags are seen, it is easily recognizable on account of the brownish-yellow colour of the surface.

The peninsula west of the Tarmfjord. Outermost on the peninsula, the tillite rests on light-reddish quartzitic sandstone. The basal part of the tillite, about 2 m, is a dark, greyish-brown, coarse sandstone, which carries a few erratics. The tillite above it is dolomitic.

Loc. No. 9. The basal bed of the tillite has a somewhat lighter, green, colour. The brownish-yellow dolomitic tillite above it contains at different levels layers of well stratified, red-violet mudstone, in which some straggling erratics and also some thin layers of dolomite gravel may occur (see Pl. 4). This red-violet mudstone appears as irregular lenses of more or less extent. The tillite may also in places be red-coloured.

Over the dolomitic tillite which is 8 m à 10 m in thickness, comes greyish-green tillite, 15 m à 20 m. Then again, dolomitic tillite and greyish-green tillite, and then once again the same group. The whole thickness is 70 à 90 m. Some red and green shales are sometimes seen. The border planes between the groups are distinct, but I have not observed any special shearing of the rocks. Meanwhile, it must be supposed that the conditions are analogous with those on the peninsula between the Tarmfjord and the Smalfjord, where positive thrust planes are observed, partly with, partly without

shearing of the rocks. Consequently, the tillite is probably tripled on account of overthrusts.

Loc. No. 10. The tillite has a basal zone of sandstone, of 10 à 15 m in thickness. Lowermost, the sandstone is dark-coloured, higher up, lighter, it is coarse-grained and contains irregular layers of conglomerate, chiefly of dolomite pebbles, generally of a size like a nut.

Loc. No. 11. About where the road runs across the height from the Tarmfjord to Vestertana, the greyish-green tillite rests on a light-coloured sandstone direct. I cannot say whether this sandstone belongs to the older sandstone series, or whether it is to be regarded as the basal beds of the tillite-bearing series.

Slight traces of stratification of the tillite are often seen near the road down to Vestertana.

Farther southward, the tillite is constantly greyish-green. In the district west of Langryggen, about 6 km SSE of the head of Vestertana, the thickness of the tillite has greatly diminished. The underlying light-coloured sandstone and the overlying red-brown shale and sandstone at several places lie nearly in contact with each other. In the river-cut of the river from Tennevann, the thickness is not more than 5 m. The rock is, however, in this area, to a rather high degree covered with loose deposits.

On the east side of the oblique anticline from Çokkales (loc. No. 7) and southwards, the tillite stands nearly vertically, somewhat inverted, with light coloured quartzite west of it, and red shale and sandstone east of it. Just east of Langryggen the upper tillite also occurs.

Suorõcejok (Sect. Fig. 29). The lower tillite is visible on the shore at Skjærneset (loc. No. 12). The upper tillite lies at the top of the mountain side, the layer dips towards the west. At the mouth of Suorõcejok, the upper tillite is seen at the bottom of the valley. The mountain side west of the head of Vestertana, consists of red and brown shale and sandstone which are more or less strongly folded. It would be very difficult to make measurements of the thickness of the zone, but I estimate the thickness to be some hundred metres.

The road-cuts about 1 km west of the mouth of Suorõcejok, present good opportunity for studying the upper tillite and the adjacent



Fig. 29. a light-coloured sandstone, b lower tillite, c red and brown sandstone and shale, d upper tillite, e dark shale and light sandstone, f red-violet shale and blue-green shale.

layers. The shales just below the tillite are of green colour; they are less folded close to the tillite than farther away. The actual border plane is entirely conformable with the bedding planes of the shale and of the same character as these. In the tillite, traces of stratification are present. Further, as regards the rocks above the tillite, the gradual transition from tillite to shale is clearly visible.

The colour of the tillite is here dark greyish-green. Most of the erratics are of Pre-Cambrian crystalline rocks. The tillite rock has a marked schistosity and the erratics are often cut by parallel joints filled with calcite, along which some glide may have taken place.

On the peninsula north of Suorõcejok, the strata lie fairly flat, but on the western side the tillite rises to a steep, somewhat inverted position, forming the eastern side of a large, oblique anticline. The tillite is seen as a marked ridge running towards the SSW, the bed being constantly inverted. The thickness of the tillite is at least 50 m.

The Njukõagaissa district. In the anticlinal valley west of the tillite ridge just mentioned, the rocks are chiefly red-brown shale and sandstone. The anticlinal axis mounts towards the SSW; the lower tillite appears west of the river at a point about half the distance between Vesterbukt and the top of Njukõagaissa. The tillite rests on light-coloured white sandstone. The thickness of the tillite is here 15 à 20 m; comparatively much of stratified layers is seen in the green-coloured tillite. The river bed cuts along the yellowish-red dolomitic shales just above the tillite, i. e. just east of it, the dip of the strata being vertical.

Fig. 30 shows a section from a locality 6 km NNE of the top of Njukõagaissa. The strike of the rocks in N 25°—30° E, the section being cut at right angles to the strike. To the west, the lower tillite is overlaid by the red-brown shale and sandstone, which are strongly folded except near the tillite. Instead of the yellowish-red dolomitic

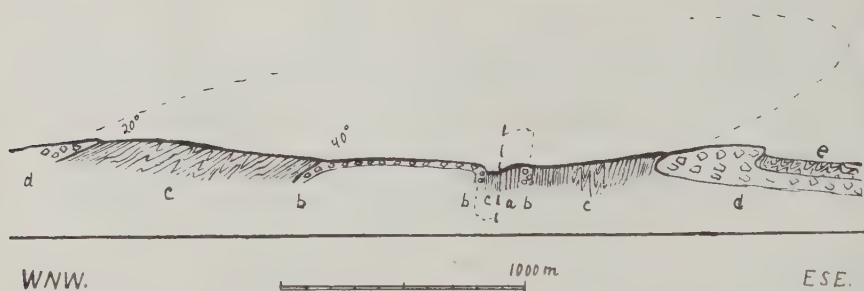


Fig. 30. Section about 6 km NNE of the top of Njukēagaissa.

a light-coloured sandstone, b lower tillite, c red and brown sandstone and shale, d upper tillite, e dark-coloured shale.

shale, the basal beds of this zone here consist locally of yellow, impure dolomite, of about 5 m in thickness. The upper tillite forms the ridge west of the valley.

The river bed is eroded in the yellowish red dolomitic shale, the dip of the strata is vertical. Just east of the river, beds of white quartzitic sandstone occur, evidently on account of tectonical movements. Then the lower tillite appears again, bordered to the east by yellowish-red dolomitic beds. Farther eastward, the rocks are red and brown shale and sandstone, and in the ridge Harjas east of the valley, the upper tillite occurs, with a somewhat inverted position.

This is perhaps the most favourable place of a sort for measuring the thickness of the zone between the tillites. The dip is vertical; by pacing, I have found the distance between the lower and the upper tillite to be about 400 m, but as the thickness is probably increased on account of folding, this is a maximum thickness. However, also considering other localities in the Vestertana-Njukēagaissa districts, the thickness cannot be less than 200 m. I cannot determine the thickness with more accuracy than $300 \text{ m} \pm 100 \text{ m}$.

The Njukēagaissa mountain consists of light-coloured quartzitic sandstone belonging to the older series, but the layers form an oblique anticline; they dip towards the west and, on the east side of the mountain, are somewhat inverted (see Holtedahl, 1931, p. 263). On this side, the lower tillite rock is strongly sheared, and, as also shown by Holtedahl, more to the south the tillite disappears and the light-coloured sandstone is seen nearly in contact with the red-brown shales and sandstones, the series being separated only by a

10 m broad belt of loose deposits. But, near the southern end of the quartzite, a crag of the lower tillite occurs. Also on the west side of the southern part of Njukēagaissa the tillite does not occur. Consequently, the thickness of the tillite must have decreased, as, otherwise, the tillite is the rock most resistant towards tectonical disturbances and towards weathering.

On the river bed south of Njukēagaissa, there is quartzite on one side and red-brown shale and sandstone on the other, but no tillite. Here, however, a dislocation line seems to run in the direction E—W.

Njukēagaissa — Vaddasbakte. Westward from Njukēagaissa the upper tillite forms a broad belt. The folding axes dip slightly towards the north, where we find younger beds, whilst to the south the red brown shale and sandstone form the rock underground of a plain, extending to the southern border of the sediments.

The tillite forms oblique folds, the direction of the folding axes is $N 10^{\circ} - 20^{\circ} E$. The tillite has always a distinct schistosity with rather steep dip towards WNW (see Fig. 45). The tillite ridges are almost always steep-sided to the east and slightly sloping to the west on account of the schistosity and the oblique folding. As the erosion has often cut away the acute ridge of the anticline, the underlying strata are seen (see Fig. 44). Most often the transition from these beds to the tillite is normal, but some thrusting of the tillite on the shale and sandstones seems also to have occurred, the contact being in a number of cases unconformable. A decrease of the thickness of the upper tillite is observed westwards. North of Njukēagaissa, the thickness is at least 50 m (a river-cut west of the valley, at about half the distance from Vesterbukt to Vestertana); but at Traneelven ($70^{\circ} 20' N. L., 16^{\circ} 36' E$ Oslo) the thickness is 10 m, at most 15 m. The river there cuts the tillite and the adjacent strata, the border conditions are entirely normal.

In the district east of Vaddasbakte the thickness of the tillite is at most 10 m. The tillite there carries only few and small erratics, about exclusively of Pre-Cambrian crystalline rocks. (I have, however, observed an angular boulder 1.5 m in diameter of Pre-Cambrian rock.) The colour of the tillite is distinctly green; in the upper part of the bed the groundmass is partly stratified, whilst the erratics are irregularly scattered.

The stage of dark shale and light sandstone above the tillite occurs north of the tillite belt. This stage is characterized in the landscape by a chain of small lakes and short streams.

The tillite curves to NW, and the rock west of it is red-brown shale and sandstone. The beds are strongly folded, but the stage as a whole partly lies rather flat. The sandstone beds are usually not more than 20 cm in thickness. Very coarse material does not occur.

The rocks at the top of the Vaddasbakte mountain belong to the metamorphic complex and are separated by a distinct thrust plane from the underlying rocks, which are light-coloured sandstones belonging to the older series. The latter, broadly speaking, forms an oblique anticline with inverted, steep position of the strata on the east side. Ridges of the lower tillite occur on the southern side of the hill; the tillite rests on the light-coloured sandstone. Also on the eastern side, portions of the lower tillite are observed; here, however, tectonical disturbances are important, the tillite may be enclosed in the light-coloured sandstone; but I have also observed normal contact between the light-coloured sandstone and the tillite.

The thickness of the lower tillite cannot be measured, but, as the tillite here is rather conspicuous, the thickness must be at least 15 m, probably considerably more.

The colour of the tillite is grey; the erratics consist, as far as I have seen, of sandstone and quartzite only. The abundance of rounded pebbles is peculiar, but angular stones are also common, and they lie altogether unarranged in the groundmass; the rock has the usual character of a tillite.

The actual border between the red-brown shale and sandstone and the tillite has not been observed on account of the loose deposits in the valley along the border.

7. The Further Sequence up to Basis of the Fossiliferous Stage.

The section Stappogiedde—Duolbasgaissa gives a general view of a considerable part of the sequence younger than the upper tillite. The section runs along the side of the little valley just NE of Duolbasgaissa. The strike of the rocks is NE, the strata have a moderate dip, most often 20 à 30°, towards NW. I have determined the thicknesses by continuously measuring the height

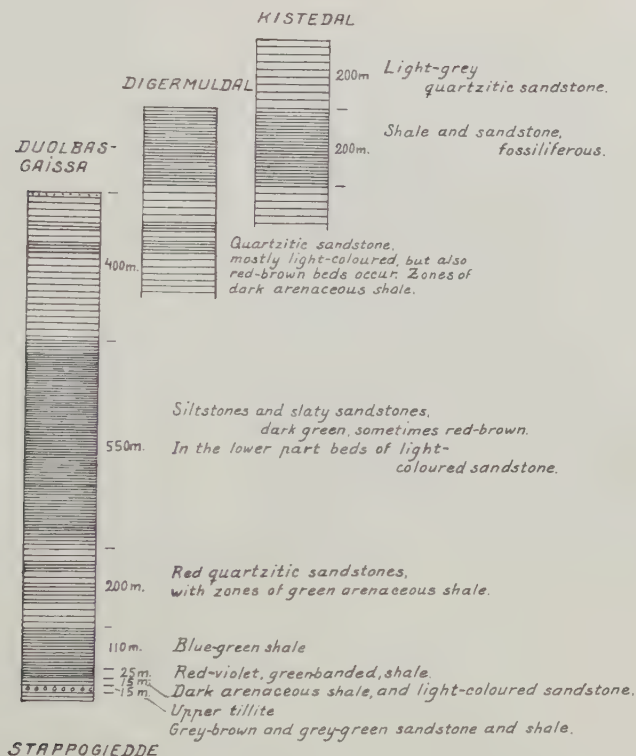


Fig. 31.

above sea-level by means of an aneroid barometer and at the same time noting the dip of the strata; the lengths along the section have been taken from the map. Even if the thicknesses of the different zones with this method may be somewhat inexact, the errors will, essentially neutralize each other so that the total thickness will be approximately correct. The section represents a formation of about 1300 m, younger than the upper tillite. The different parts of the sequence are characterized in their broad features on the diagram, Fig. 31.

The upper tillite is seen at Stappogiedde along the shore, inside of which there is a strip of cultivated land (a quaternary shore line). At the foot of the mountain slope, the red-violet shale occurs and passes into the bluish-green shale. The thickness of the shale stage is between 120 m and 150 m.



Fig. 32. Section across the Digermul Peninsula.

The section includes the series from the upper tillite (at Stappogiedde on the Vestertanafjord) to the fossiliferous stage (east of the Nova mountain).

1 km farther to NE, at the mouth of the stream, beds, of greyish-green sandstone, are also seen below the tillite. Above the tillite, beds of dark arenaceous shale and light-coloured sandstones occur, and thereupon the red-violet shale, etc. The thickness of the tillite is about 15 m, and has consequently decreased from the district west of the head of the Vestertanafjord. The shale and sandstone stage above the tillite is also about 15 m in thickness.

The stage above the bluish-green shale attracts attention by beds of a vivid red colour, occurring as three zones separated by greyish-green arenaceous shale. The thicknesses, measured at Stappogiedde are:

At top: 25 m red quartzitic sandstone.

25 » greyish-green slaty sandstone and arenaceous shale.

35 » red quartzitic sandstone.

40 » greyish-green arenaceous shale.

70 » red quartzitic sandstone.

The red colour of the lowest, thickest sandstone zone is very vivid, that of the other is palish and some beds are rather light or slightly greenish. The beds may be 1 m in thickness but they are most often 10—20 cm. The bedding is due to layers of micaceous sandstone or to very thin layers of clayey material. Within a bed the lamination is only slightly visible. Ripple marks are common. The rock is very fine-grained, the fracture looks glassy.

A thin section shows a very even-grained rock. The grains are of 0.04—0.07 mm in diameter. The chief mineral is quartz; the original borders of the grains are rounded. Further, plagioclase (partly sericitized, partly fresh) and muscovite occur, thereon a few grains of zircon and tourmaline. The colour is due to finely divided dust-like material which reflects the light red.

These red zones are conspicuous in the landscape, they are seen from a long distance. Joints in the rocks are very often filled with

white quartz, therefore the fractures of the beds may be white in colour.

At Stappogiedde the transition between the bluish-green shale and the red sandstone consists of loose red shale; in other places, especially in the district east of the Ifjord, the basal beds of the sandstone is a light-coloured, conspicuous bed of sandstone, which lies directly on the bluish-green shale.

The greyish-green zones between the red consist of arenaceous shales and slaty sandstones, often micaceous. They may in some cases resemble very much the underlying bluish-green shale, and also the overlying rocks, which will soon be described.

The thickness of the different parts of this zone seems to vary from place to place, but I can give no figures for the variation. In the district between Vestertana and the Ifjord, the development is like that of Stappogiedde, i. e. with three zones of red sandstone and intervening zones of greyish-green shale. But this development seems to differ from that in the hills east of the Tana River, where the red quartzitic sandstone is very common. According to H. Rosendahl (1931, p. 493), there occurs a uniform zone of red quartzite of at least 150 m in thickness. Above this, comes a greyish-green shale zone, which in the lower part is a micaceous sandstone. This is connected to the red quartzite by transition rocks. It is now an open question whether this uniform zone of 150 m red quartzite corresponds to the three zones of red quartzite and intervening shales together, or whether it only represents the lowest quartzite zone at Stappogiedde.

We are going further up to the stratigraphical sequence at Stappogiedde. Over the rocks just described, there occurs a zone of shale of more than 500 m in thickness. The rocks resemble the bluish-green shale, but they are a little more arenaceous and of a

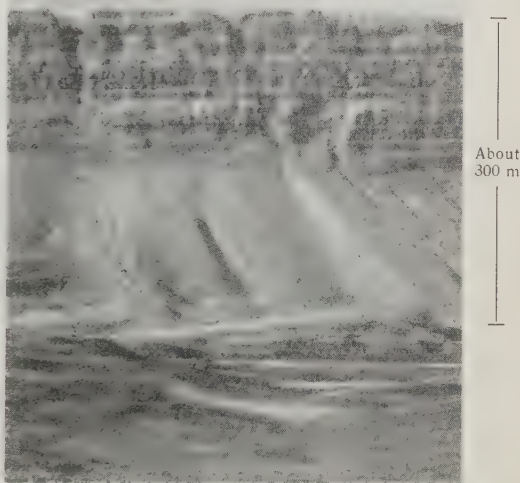


Fig. 33. The mountain wall of Duolbasgaissa, seen from the south.

more greyish-green colour, in some cases somewhat reddish. The lamination appears on the planes of schistosity as bands of slightly differing colour-tone. In the lowermost part of the stage, some beds of sandstone occur; they are usually rather thin, but beds of 1 m in thickness are also observed.

Also the uppermost part of the shale stage is more arenaceous, and again real sandstone beds appear. There is a gradual transition to the next stage which forms the precipice of the plateau.

At top: Brownish-violet conglomerate.

50 m. Sandstone. In part white, in part brown-violet.

20 » White quartzitic sandstone.

20 » Slaty sandstone. Brown débris.

20 » White quartzitic sandstone.

40 » Slaty sandstone. Brown débris.

90 » Light-coloured quartzitic sandstone in thick beds. Upper part white, lower part reddish.

150 » Sandstones, of light and dark colour alternately. Comparatively thin beds, seldom above 0.5 m.

The light-coloured quartzitic sandstones dominate. The beds may have a thickness of several meters. Besides the entirely white sandstones, all transitions to dark brown-violet and to greyish-green sandstones occur. Between the white sandstones the slaty rocks appear as dark zones, as they are more easily weathered and the débris has a brown rust colour.

In the uppermost part of the stage, "problematic trails" are very common, irregular pipes which in some cases lie in the bedding planes and in others, cut the bedding. I have not observed such trails in the older parts of the series.

The uppermost horizon in the sequence here observed is a peculiar conglomerate. The groundmass is a brown-violet sandstone, the pebbles are small, usually less than the size of a pea. The pebbles consist of quartz, further, of a red jaspoid rock and of yellowish green shale. They are rounded, except the shale fragments which are flat though they also have rounded edges. The shale fragments weather away comparatively easily.

As examples, two thin sections from the rocks of Duolbasgaissa will be described:

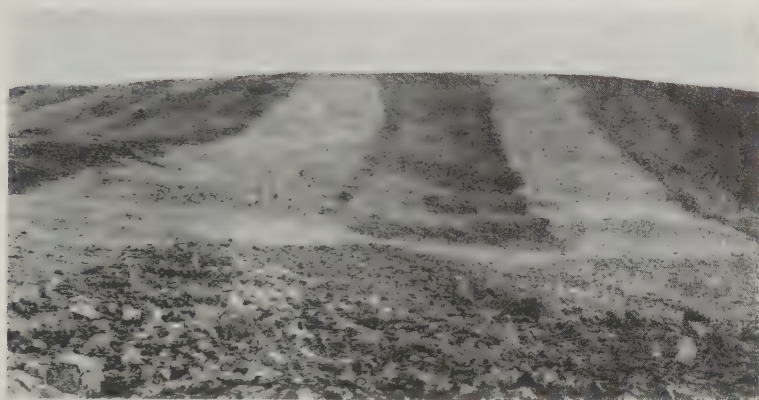


Fig. 34. White quartzite beds between dark sandstones. The loose material consists almost exclusively of rocks from the underground. Western part of the Duolbasgaissa plateau.

1. White quartzite, consisting nearly exclusively of quartz. Size of grains from 0.1 to 0.3 mm in diameter. The present borders of the grains appear as dark irregular lines, whilst the original well-rounded shapes are marked by more indistinct lines. Some greenish grains are probably decomposed felspar.

2. Brown-violet sandstone. The grains slightly rounded. Chief mineral, quartz, further, plagioclase and grains of colourless mica and of zircon. The quartz grains may be divided into two groups of sizes, one of diameter about 0.3 mm, the other and larger of diameter about 0.1 mm. The plagioclase, the sizes of which are about 0.1 mm, is rather strongly decomposed into sericite and chlorite. Some greenish grains probably represent entirely changed plagioclase. Between the grains, iron-ore is abundant, enclosed in the secondary quartz matter.

D. The Fossiliferous Stage.

The mountain mass of the Digermul Peninsula and the continuation of the mass towards SW, have been the subject of only brief examinations, except the section of Stappogiedde. It is, however, rather easy to obtain a general view of the rock formations, as loose deposits and vegetation are almost absent. On the south-eastern side of the peninsula, the tectonical conditions are rather clear: the zones of the Stappogiedde section sink towards NE, and reach the sea

level successively. I have qualitatively controlled the sequence in going by motor-boat along the shore.

On the north-western side of the peninsula, the tectonical conditions are not so clear. On account of the short time which was at my disposal, I had to content myself with recording the main features of the stratigraphical and tectonical development. As fossiliferous Cambrian sediments occur here, a detailed examination of the Digermul Peninsula would be the more desirable, as we might thereby obtain more material to settle the lower limit of the Cambrian system.

I went by motor-boat along the Langfjord. I found the first fossils — brachiopodae with concentric striae — in loose pieces of rock on a quaternary shore terrace at the mouth of Boksjokka near the head of Langfjord. By searching along the river bed I found fossils in solid rock, at a place about 5 km SE of the river mouth. After having examined this locality and collected a number of fossiliferous rock specimens, I returned down the fjord. Only three excursions on shore were made, namely in the valleys Hånsvikdal, Kistedal, and Digermuldal. On another journey, I went down the Langfjorddal valley to the head of the Langfjord and then crossed the peninsula to Stappogiedde.

In 1933 O. Holtedahl made an excursion by motor-boat in the Langfjord. He then took some photographs of which he has most kindly permitted me to make use.

The fossiliferous stage is well marked in the landscape. The rocks are dark shale — green, grey or black, sometimes with a yellow coat — and dark sandstone alternately. The thickness of the sandstone beds does not usually exceed 5 cm. The rocks are easily eroded and the stage therefore forms extended depressions; the rock is often covered with loose deposits so that outcrops are chiefly found in the river-cuts.

In the Boksjokka river-cut the fossils were found in solid rock at nearly each step within a distance of several hundred metres, that is several tens of metres of the sequence, the beds dipping about 15° (towards NW). The fossils are chiefly found in the sandstone beds, but also occur in the shale. Some beds are very rich, real fossil breccias, others contain but few fossils and some are empty. Fossiliferous rock is common among the loose pieces in the river.



Fig. 35. Fossiliferous sandstone and shale. The Boksjokka river.

The material collected has been examined by Dr. phil. Trygve Strand (1935), according to whom the fossils are:

Lingulella (*Lingulepis*) cf. *Roberti* (Matthew).

Billingsella cf. *retroflexa* (Matthew).

Hyolithus sp.

Trail of *Cruziana* type.

The *Lingulella* species is the prevailing fossils; of the other brachiopod, only a few specimens are found. The single hyolithus fragment is badly preserved. The two brachiopods are of Middle Cambrian — possibly Upper Cambrian — age. For the accurate description and the determination of the age, I refer to the paper by Dr. Strand.

My observations at different places, especially in Digermuldal valley, determine that the fossiliferous stage follows immediately on the stage of light-coloured sandstone described from Duolbasgaissa. The conditions being unfavourable, I did not measure the thickness of the fossiliferous stage; moreover, in a number of cases the stage seems to have doubled itself up, and overlying beds are observed only at one place in the Kistedal valley. But in my opinion — considering the extension of the stage at different places — the thickness is about 200 m. The overlying rock — greyish quartzite — in Kistedal seems to be of about the same thickness.

The shale of the fossiliferous stage has, in contrast to all the older shales, no slaty cleavage at an angle to the bedding; and yet

it must have been exposed to a considerable lateral pressure during the forming of the isoclinal folds. The cause is probably not any difference in the tectonical conditions (as e. g. less vertical pressure), but an original difference in the nature of the sediments. Now, it is a fact that no secondary cleavage will be developed where shale and sandstone rapidly alternate; but there are in this stage also considerable zones of pure mudstone, which also splits along the bedding planes. The cohesion vertically on the bedding planes in this mudstone is consequently so small that the rock yields along the bedding. But in the older shales the cohesion vertically on the bedding planes is so great that the attitude of the cleavage planes will depend on the direction of the stress, even when the grade of the material is distinctly different from bed to bed.

The fossiliferous stage, like the other sediments, is deposited in shallow waters. Mudcracks are often seen, and problematic trails (irregular tubes) are also common.

The Various Localities.

The Digermuldal valley (Pl. 1, Fig 3). The cliff on the point of the peninsula is built up of the greyish-green shale, which at Stappogiedde is about 550 m in thickness. The dip of the beds is slightly undulating, but on an average the beds around the point dip inland and thus form a trough. Close to the water-line, some beds of light-coloured sandstone are seen, belonging to the lowermost part of the shale stage. One thick bed of light-coloured sandstone is also seen high up in the shale and on the top, the light-coloured sandstone stage of Duolbasgaissa appears. Along the Langfjord, the beds gradually sink and, towards the Digermuldal, the light-coloured sandstone stage approaches the water-line. In the Digermuldal, the beds to NE form the sides of a trough, the strike of the sloping beds, curving. The trend of the folding axes is NE. 1.5 km up the valley, the following sequence is seen, from the top downwards:

White sandstone

Brownish slaty sandstone

White sandstone

Shale, brownish débris

White sandstone

Reddish sandstone

Sandstone of darker colour.

In the cut of the river from south, the same succession and its continuation upwards appear. The strike is about N, the dip about 35° to W. The uppermost beds gradually grow darker, a little dark slaty sandstone and beds of brown-violet quartzitic sandstone occur and then again beds of a more light colour. Ripple marks and mudcracks were observed.

On comparing, accordance is found with the stage of Duolbasgaissa (page 106 and diagram Fig. 31). The brown violet conglomerate, however, is not observed.

Above the light-coloured sandstone comes the fossiliferous stage. The lower part consists of alternating beds of green shale and arenaceous shale, and also grey sandstone beds. Some thicker beds of quartzitic sandstone also occur. Higher up, the shales are black and split thinly, and have often a rusty coat on the bedding planes. I found some loose pieces of rock with fossils (*Lingulella*), but did not search any particular time for fossils in solid rock.

Kistedal. The main valley is eroded in the fossiliferous stage; fossils (*Lingulella*) were observed in the river-cut about 2.5 km off the river mouth. In shore gravel I found the piece of rock with trail of *Cruziana* type (Strand 1935).

The south-eastern flank of the valley consists of a light grey, thick-bedded, quartzitic sandstone. Lying apparently above the shale, this quartzite seems to be a younger stage of the series. The thickness of the whole quartzite seems to be about 200 m. The sandstone forms a syncline which is cut by the lateral valley from SE. The quartzitic sandstone consists chiefly of quartz, of very equal grains 0.10—0.15 mm in diameter; tourmaline and zircon occur accessorially.



Fig. 36. Light-coloured sandstone with zones of arenaceous shale. About 1.5 km in the Digermuldal valley.

The actual coast of the Digermul Peninsula towards the Langfjord, represents practically the thrust plane below the metamorphic rocks. Traces of strong tectonic movements are often seen in the mountain side along the fjord. Broadly speaking, the disturbances imply a turning over of the Duolbasgaissa sandstone, this forming an oblique fold, the sandstone thus in a number of cases lying over the fossiliferous stage. Between the Kistedal and the fjord a plate of metamorphic rocks lies obliquely, with the dip NW. Below it, occur beds of quartzitic sandstone, inter alia of brown-violet quartzitic sandstone and of arenaceous shale; the whole of it belongs to the stage below the fossiliferous stage.

In the mountain side east of the outer part of Kistedal, the sandstone seems to form two oblique anticlines, with dark shale rock (the fossiliferous stage) between them and within the inner one.

Hånsvikdal. (Sect. Fig. 32.) On the sides of the valley the oblique folding is very well seen. The mountain Nova is built up of the Duolbasgaissa sandstone, the beds forming the upper part of the letter S. At the top the folds are so acute that the beds are broken. Some distance west of the mouth of the valley, dark-coloured shale is seen below the light-coloured sandstone. It possibly belongs to the 550 m thick shale stage below the sandstone stage.

The valley further cuts through the fossiliferous stage. I determined the presence of fossils in solid rock; the fossiliferous beds are, however, not very rich.

In the fossiliferous stage, all the beds of which dip to NW, two strokes of thick-bedded sandstone are noticed. It is obviously one and the same layer in the isoclinal fold.

Below the shale, the quartzitic sandstone appears, damming up the small lake "(138)". One notes the reddish, in part, rather brown-violet, quartzitic beds in the upper part of the light-coloured sandstone.

Boksjokka. (Sect. Fig. 37.) The sandstone most south-easterly of the section is generally light-coloured and thick-bedded; some beds are of red-violet colour. The rocks resemble those of Duolbasgaissa; thus beds bearing "problematic trails" are found. On an excursion across the peninsula, I found that the sandstone really corresponds to the Duolbasgaissa sandstone. It forms the rock under-

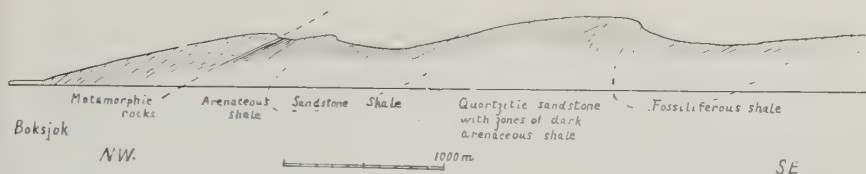


Fig. 37. Section along the Boksjokka river.

ground of the central part of the peninsula; the beds are slightly or moderately folded; the solid rock is in a degree covered with coarse débris consisting of the rocks from the underground.

The dip of the fossiliferous shale is constantly about 15° , towards NW. The depression is about 1 km broad; it is on NW flanked by a ridge consisting of light-coloured, thick-bedded sandstone, containing a zone of dark arenaceous shale. Close to the depression the dip is nearly vertical, for the rest, the beds dip NW, moderately, though irregularly.

Some beds of reddish colours occur, in such red-violet beds I found a conglomerate quite similar to that of the top of Duolbas-gaissa. The conglomerate layers or lenses are intercalated in the sandstone, being at most 10 cm thick.

NW of the sandstone ridge, another bottom extends in the direction of the strike. The rocks are similar to those of the fossiliferous stage, but, in spite of close search, I have found no fossils. However, I suppose the rocks belong to the fossiliferous stage, the sandstone ridge between the bottoms forming an oblique, rather acute anticline as seen on the mountain side of Nova, on Hånsvik.

The ridge NW of the outer bottom also consists of sandstone, the stratigraphical position of which I have not conclusively proved. The beds constantly dip NW, the sandstone for that matter lying over the shale of the bottom, but probably there is again an isoclinal fold. So near the border of the metamorphic rocks tectonical disturbances have play in a greater degree; thrusts and zones of crushed rock are common both in the sandstone ridge and in the arenaceous shale between the ridge and the metamorphic rocks.

The metamorphic rocks are strongly distinguished from the unmetamorphic; and the border plane is a distinct thrust plane.

E. The Southern Border of the Sedimentary Rocks.

In Western Finnmark the sedimentary rocks rest upon a Sub-Cambrian peneplane. In Eastern Finnmark, however, — from the Antebaktoaivve mountain ($16^{\circ} 30' E$ Oslo) to the Varangerfjord — the border of the sediments has quite another character: the sediments seem to have been deposited upon a rather uneven surface of the Pre-Cambrian crystalline rocks (stated by A. Dal, A. Strahan, and O. Holtedahl, see Holtedahl, 1918, p. 11 and p. 158). The northern limit of the Pre-Cambrian rocks seems to have a rather straight W—E direction. The sediments which are extending south of this line belong to the younger, tillite-bearing series. The border plane between the crystalline rocks and the older sandstone series is obviously more or less steep. O. Holtedahl (1918, p. 264, and 1931, p. 269) explains the conditions in Eastern Finnmark in this way: After the deposition of the older sandstone series a dislocation must have taken place along a line in the direction of the Varangerfjord. South of this line a highland has arisen which has then been exposed to erosion. At first, the erosion took place in the sedimentary rocks, but gradually it got to the crystalline basement. The material was washed over the area to the north. At least, sedimentation has also taken place in the area south of the fault line, first filling the depressions of the uneven surface.

1. *The Čikkajok District.*

With this term I mean the district near the southern border of the sedimentary rocks from Skipagurra (on the Tana River) westward to Menavarre (the hill "286", about 10 km east of the Antebaktoaivve mountain). The area has been visited and described by O. Holtedahl (1931, p. 258); the statements I give in the present paper are chiefly of interest because I can draw a comparison with the sequence of the Tanafjord district.

The exploration of the rock presents difficulties, the rock surface being very moraine-covered. Rock exposures are to be found almost only where late-glacial currents have washed down the gravel.

Comparatively well exposed are the Pre-Cambrian rocks in the hills between the valley of the sediment border and the valley of the Tana River. I have made no close examination of these rocks



Fig. 38. The flat, moraine-covered area between the Njukāgaissa mountain and the Čikkojokka river.

and only occasionally have taken specimens for a comparison with the erratics of the tillites. The chief rocks are: Biotite gneisses containing portions of a coarse, reddish granite; hornblende gneiss with dark, hornblende-rich portions; a somewhat gneissose gabbro, with as chief minerals plagioclase, hornblende and epidote; some portions of the rock consist almost exclusively of pyroxene and hornblende.

Real contact between the crystalline rocks and the sediments has not been observed. There can hardly be any doubt, however, that the surface of the crystalline rocks was an uneven one at commencement of the sedimentation, tongues of sedimentary rocks extending south in the Pre-Cambrian area, filling valleys. It can be seen between Ravddovarre and Fallenjoaskvarre; if a line is thought to be drawn between the tops of these hills it will pass above the top of the tillite hill (the "204" m hill. See section Fig. 39). And, likewise, an imaginary line between the tops of the two tillite hills on both sides of Ravddovarre, will cut the last-mentioned hill. The basis of the sediments is, of course, still lower; west of Ravddovarre, the visible thickness of the tillite is about 30 m, east of Ravddovarre, the tillite rests on coarse sandstone.

In addition to the outcrops of the lower tillite just mentioned, this rock is observed in the river bed of Čikkojok and in the "176" m hill north of the river, and also at a locality SE of Menavarre. That all these tillite outcrops are of the lower bed, will later be confirmed. The tillite outcrop NE of Skoarrovjavre is probably the lower tillite;

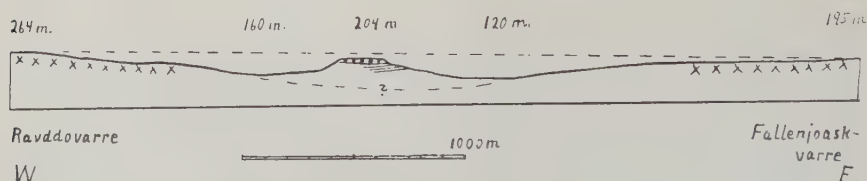


Fig. 39. The sediments has been deposited in the depressions of the surface of the crystalline rocks.

the tillite of Lismavarre is the upper. Somewhat north of the sediment border the upper tillite occurs west and east of Maskejavrre.

The sandstone beds below the tillite of the "204" m hill lie nearly horizontally, with only slight dip towards the north. The beds may be above 1 m in thickness, some of them are distinctly stratified, others are quite massive. The colour is dark grey. The minerals are quartz, microcline, acid plagioclase, green biotite, muscovite, garnet, and, in less quantity, rutile, zircon and magnetite. The size of the grains varies, the quartz grains being up to 5 mm in diameter. The grains are somewhat rounded. All the minerals are fresh. The matrix is of green colour and consists of chlorite minerals. In thin sections the lamination appears chiefly as dark lines, due to the concentration of magnetite.

In the "176" m hill the tillite rests on light-coloured sandstone. At the foot of this hill, beds of dark, thin-splitting shale appear. The dip is 5 à 7° , towards NW; the vertical distance between the river level and the tillite is about 80 m. The white sandstone contains quartz and acid plagioclase in about equal amount. Size of grains on an average 0.3 mm in diameter.

Cand. real. A. Samuelsen has informed me that east of Menavarre, about 6 km WNW of Ravddo varre, he observed tillite on a lower level than the gneiss, which extends northward, west of the tillite. Actual contact was not observed, but there was apparently no room for any sediments below the tillite.

The Čikkojok river presents the best opportunity for studying the tillite. The visible thickness is about 20 m, underlying strata are not seen. The colour is red-brown and only subordinately green, especially in the uppermost part. The erratics consist exclusively of Pre-Cambrian crystalline rocks; the size may be up to 2 m in diameter. Boulders of a size greater than 1 m are, however, rare. The overlying strata show that the tillite bed is lying nearly horizontally,

with only a slight dip towards NNW. Between this locality and the "204" m hill there is a plain, sloping only very slightly towards north; it is covered with gravel, but there is very little doubt that the rock underground is made up of the tillite bed.

Upwards the amount and the size of the erratics in the tillite decrease, the material gradually growing stratified; the rock shades into loose shale, of greyish-green colour, in part rather dark. Higher up, beds of micaceous sandstone, mostly of dark colour, occur. Some beds consist of very coarse material, with angular grains of quartz and felspar, of size up to that of a pea. Current bedding appears in some layers, and, likewise, ripple marks.

A thin section of the coarse sandstone shows as chief mineral quartz and acid plagioclase, most often fresh, in part somewhat sericitized. Further, some muscovite, biotite, iron ore, carbonate, and also small grains of zircon and rutile. Size of the grains is variable, max. diameter is 1 mm. The grains are most often angular, only in a few cases slightly rounded. The scanty matrix is greyish-green, it consists of mica, chlorite, and carbonate.

This zone of sandstones and shales is observed only at this place. The thickness may be about 50 m. The beds are unfolded, the dip is 5° à 10° , towards NNW. But above this zone comes another which is very strongly folded. The trend of the folding axes is about W—E, yet somewhat irregular. At first there occur red-brown shale with thin layers of dolomitic material, higher up, red-brown shale and grey-brown sandstones in rapid alternation. The sandstone beds predominate. They may be of a thickness of more than 1 m and consist of coarse material. There can be no doubt that these rocks belong to the well-known stage between the tillites.



Fig. 40. The Uvjaladnejojokka river cuts the plain to a depth of about 60 m. The rocks are red-brown sandstone and shale.

On the high plateau north of Čikkojok, we meet the same rocks at several places where late-glacial currents have washed down the quarternary deposits. This is especially the case SW of Maskejavrre, where the rock surface is washed in an area of several square kilometres, and a system of canyons has been cut through the plateau. The strike of the folding axes is about N 40° E.

In the river cut just north of "177", we have a good section through the upper tillite, which is lying inverted, with dip 40° à 50°, to WNW. I estimate the thickness at about 50 m. The older part is red-brown, and rich in boulders. The erratics consist exclusively of crystalline rocks. The size of the erratics is on an average larger than that on the Tanafjord. A number of the blocks has a quite irregular shape, thus I observed a gneiss fragment about 1.5 m in length, and 30—40 cm in breadth. The material is entirely unstratified. The younger part of the tillite is greyish-green, and is not so rich in blocks.

Between the tillite and Maskejavrre the easily recognizable "red-violet shale and bluish-green shale" occurs. It is very strongly folded. It is best seen in the two short canyons north of the river outlet in Maskejavrre. Lowermost in these canyons, and also lowermost on the mountain side north of them, beds of coarse sandstone and of dark shale are seen, belonging to the stage close above the upper tillite.

East of Maskejavrre there occur some ridges of tillite, with red-brown sandstone and shale between them. The northern part of the Maskejavrre mountain is built up of bluish-green shale; the very top "317" consists of the overlying red quartzite. The rocks lie fairly flat with only a slight dip towards north or north-east. In the mountain side rather massive beds are seen.

We now return to the sediment border. Between Skoarrojavrrre and Lismajavrre the crystalline rocks terminate in a steep slope, and north of the valley, on the same level, red-brown tillite occurs and, over it, dark shale. In my opinion this is the lower tillite, but I cannot state it with any certainty.

In the Lismavarre mountain, the upper tillite lies flat above red-brown shale and sandstone. Close to the tillite there is comparatively much of shale, but lower, only sandstones are seen; they are more than one meter in thickness, and the material is coarse. SE of Lismavarre there is an island of crystalline rocks surrounded by

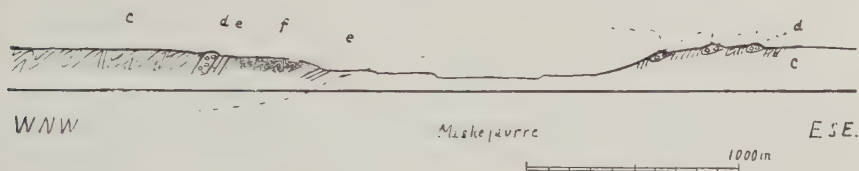


Fig. 41. c red and brown sandstone and shale,
d upper tillite, e light-coloured sandstone and dark shale,
f red-violet shale and blue-green shale.

glacifluvial material from the quaternary glaciation. Contact between the crystalline rocks and the sedimentary are not observed, but the red-brown sandstones must be supposed to rest directly on the crystalline floor, as it has been found by Holtedahl in the area east of the Tana River (Holtedahl 1918, p. 167).

North of the eastern end of Lismajávrrre the rock is washed by late-glacial rivers, the very thick beds of red-brown sandstone thereby having been exposed. The beds may be some metres in diameter; the material is very coarse; angular grains of some millimetres in diameter are seen. The strike of the folding axes varies somewhat and just north of the eastern end of the lake it is N 50°—60° E, but one km further east it is N 60°—70° E.

The red-brown sandstone with shale can be followed north to Seida; there the upper tillite is encountered on both sides of the valley. The lower part of the tillite is red-brown, the upper part is grey. Farther north, the tillite dives below the loose deposits of the valley, and the sides of the valley consist of younger beds. At the foot of the hills north and south of the outlet of the Maskjok in the Tana River there occur coarse, white or dark, sandstones, alternating with dark shale. Thickness about 50 m, thereupon red-violet and bluish-green mudstone.

I will briefly summarize what is characteristic of the two tillites and the intervening stage in the Čikkojok district, in contrast to those of the areas farther north.

Lower tillite: Red-brown colour. The erratics consist apparently exclusively of crystalline rocks. Larger maximum size of the blocks. Richer in erratics than the green tillite farther north (but not richer than the dolomitic tillite).

Close above the lower tillite occurs a zone of shales and sandstones, usually dark, the thickness being about 50 m.

Red-brown sandstone and shale: The sandstones predominate. Thickness of beds may be up to a couple of meters. The material is often coarse, sparagmitic.

The upper tillite: Red-brown colour. The erratics consist apparently exclusively of crystalline rocks. Larger blocks and more blocks. More irregular shape of the blocks.

The upper part of the tillite is green and contains not so much erratics as the red part.

2. The Antebaktoaivve District.

With this term I mean the areas round the Antebaktoaivve mountain and westward to Ulfarvarre, Ullogaissa and Stalogaissa and also northwards, west of $16^{\circ} 30' E$ Oslo, to Vaddasbakte.

Holtedahl (1931, p. 257) points out the fundamental importance of the Antebaktoaivve district for conclusions as to the relation between the Hyolithus zone and the stratigraphical sequence of the Tana district. South of the Porsangerfjord, the Hyolithus zone, which is there fossiliferous, rests with a basal conglomerate on the Sub-Cambrian peneplane; higher up, overthrust Porsanger sandstone occurs. Holtedahl has gone along the sediment border eastwards from the Porsanger district to Antebaktoaivve; the lower beds are often covered with débris, but the border seems to be a normal one. Holtedahl supposes that the rocks close to the peneplane belong to the Hyolithus zone also in the Antebaktoaivve district. We are now going to see how it appears to me, who entered the Antebaktoaivve district from east.

The exploration of the rock formations in this district is, however, beset with difficulties. East and north-east of Antebaktoaivve, the rock is considerably covered with loose deposits; west of $16^{\circ} 30' E$ Oslo, the rock is rather well exposed, but a topographical map is practically missing. The observations, made on two rapid journeys in this district, are therefore more or less casual.

Cand. real. A. Samuelsen has told me that he observed tillite just south of the "242" m hill ($70^{\circ} 9' N$ Lat., $16^{\circ} 43' E$ Oslo). North and north-west of "242" I have observed solid rock at several places; in some cases, it was the well-known beds of red-brown sandstone and shale, in others a light grey-greenish quartzitic sandstone in massive beds. Contact between these rocks is not found; but

I suppose it most probable that this sandstone belongs to the "older sandstone series", and that the lower tillite may exist between the two rocks. NE of "296" I found a dark grey arenaceous mudstone in contact with the light-coloured sandstone. Stratification is apparently missing. This sediment may perhaps be an equivalent to the lower tillite, but without any block material. A thin section shows that the grains are markedly angular, have irregular shape, the maximum diameter being 0.2 mm. Chief constituent, quartz; fresh plagioclase is common. The matrix is a grey-greenish mass, in which muscovite and a greenish chloritic mineral are distinguished.

In the south-eastern and southern part of the Antebaktoivve mountain, the light-coloured sandstone is well exposed. Thin section: Chief mineral, quartz; microcline and plagioclase are also common, further, a little zircon and tourmaline occur. The size of the grains varies, from very diminutive up to 0.5 mm in diameter, the grains being somewhat rounded. The scanty matrix consists chiefly of muscovite.

North of the Lavsejok valley, this sandstone occurs as a continuous belt. The beds are folded, the strike of the folding axes being N 15° E. On the highest of some low hills (called Menniçokka I was told), I found on the south-eastern side a section where the substrata of the sandstone are exposed: a thin-splitting shale, the lowermost part is bluish-green, higher up, the colour is nearly black. The light grey-greenish sandstone comes, with quite undisturbed contact, above the shale. The lowermost sandstone beds are 2—5 cm in thickness, the thickness increasing higher up. The thickness of the visible strata of the section is 5 à 7 m. The section goes in the direction of the strike; the beds lie horizontally and undisturbed. The débris below the exposed beds consists of shale, which is, on the whole, a chief constituent of the loose deposits of this area.

This is obviously one of the hills mentioned by Holtedahl (1931, p. 257): "some remarkable low hills, which are to a large extent made up of débris of Hyolithus shale, but which may represent material secondarily accumulated in the valley, the accumulation being later eroded by the river".

The gneiss ground south of Lavsejokka is seen as an even plain, sloping slightly towards the north. However, also north of the sediments just mentioned, a ridge consisting of Pre-Cambrian crystalline rocks extends from WSW to ENE, the highest parts of it are

Ulfarvarre and Læmonurki. The rock is well exposed. This ridge rises to a higher level than the sedimentary rocks south of it, a depression being between them. North of the ridge again, the crystalline floor is overlaid with sedimentary rocks, the succession beginning with a basal conglomerate (Holtedahl, 1918, p. 205). The peneplane slopes slightly to NW, the crystalline ground forming a wedge, bordered to the NE and W of sediments, which dam up the lake Godtekjavre. SW of this lake the basal conglomerate is exposed west of the river Gaissavaljokka. In the river bed are crags of garnet-bearing gneiss. Just west of the river the sediment border forms a steep slope, about 40 m high, the beds lying horizontal. The succession is:

d. Light grey-greenish quartzitic sandstone. On top, thick beds, the thickness decreasing downwards.

c. Débris, consisting of small pieces of green and red shale.

b. Dark-bluish sandstone. Thick beds, with some thin layers of conglomerate.

a. Conglomerate. The pebbles are chiefly quartz, they are usually rounded, but angular fragments are also present. Subordinately, granite and gneiss occur. The fragments may be up to the size of an egg. The groundmass consists of quartz, fresh acid plagioclase, microcline and some tourmaline. The grains are most often somewhat rounded.

The thickness of a+b is about 15 m, that of c about 5 m.

Consequently, we have here the same sequence as that described by Holtedahl from the sediment border some km to the east, and the same as I observed at Menniökka.

The development of the ridge Ulfarvarre—Læmonurki must be due to a deformation of the peneplane, as also expressed by Holtedahl (1931, p. 257): "There is a possibility that the peneplane (and the sedimentary beds resting on it) in that area have been dislocated through faulting." The trend of the ridge is N about 60° E; whilst the strike of the sedimentary rocks is N about 15° E, both south, east and north of the ridge. If the deformation had taken place before the folding of the sedimentary beds, the presence of the ridge would probably have affected the direction of the axes south of the ridge. Consequently, the deformation must be far younger than the fault line along the sediment border farther east.

I cannot say with any certainty whether the deformation is due to faults or to folding movements, but in my opinion the ridge is to SSE and E bordered by fault lines.

Holtedahl presumes, as previously mentioned, that the basal beds in the Antebaktoaivve district, belong to the Hyolithus zone. Further, in his opinion, the light-coloured sandstone which builds up the mountains Ullogaissa and Stalogaissa, belongs to the overthrust Porsanger sandstone. I have, however walked to the top of both the mountains without having discovered any general thrust plane. The rock is mostly the grey-greenish sandstone, some zones of arenaceous shale are also seen. The beds are rather strongly folded; however, from a distance they seem to lie nearly flat, with only a slight dip towards north, the side of the valley having about the direction of the strike.

If the basal beds belong to the Hyolithus zone, also the light-coloured sandstone must belong to it. The following observations, however, favour the presumption that the rocks belong to the older sandstone series.

About one km east of the Gaissavaljokka river, and at about the latitude of the top of Stalogaissa, I found a crag of red-brown tillite, resting directly on the light-coloured sandstone. The tillite rock is mostly unstratified, but it contains layers of red and green shale.

Thin section of the groundmass of the tillite: Quartz, fresh plagioclase, microcline, fragments of gneiss and of shale; all in a red-brown, fine-grained matrix. The grains are generally angular, some are rounded. In the thin section, faint indications of stratification are seen, at about right angles to the well-developed schistosity; the numerous micro-shear planes have highly obliterated the stratification.

North and east of Jouvvajavrreoivve the rock is to a great extent covered with loose deposits; we find peculiar ridges and hills, formed at the melting of the quaternary glacier. The rock underground consists of the thick-bedded grey-greenish sandstone, as it may be seen at the outlet of the lower Ladnojavrre lake. North of Traneelven, the loose deposits are again less abundant; the rock is the red-brown shale and sandstone, that being the well known stage between the tillites. 2.5 km WSW of Garrisgielos, in the river bed near the outlet in the larger lake, the lower tillite appears below

the red shale and sandstone. The tillite rock is a grey-coloured, arenaceous mudstone, poor in erratics.

Farther north, the red-brown shale and sandstone lie rather flat. The characteristic vividly-red colour of the basal beds can often be seen. About 3 km NW of Garrisgielos, the river from north cuts through these basal beds and the tillite. The rock just below the red shale is a grey-coloured shale; a little deeper (i.e. somewhat farther west) the usual character of the tillite appears, but the number of erratics is still small.

Still farther north towards Vaddasbakke, the rock consists of the light grey-greenish sandstone; now and then ridges of tillite are met. The actual contact between the two rocks has not been observed here.

If the grey-greenish sandstone is, as it seems to me, the same all over the Antebaktoivve district, and if the tillite crag east of Gaissavaljokka has not been placed there by tectonical movements, the grey-greenish sandstone must belong to the older sandstone series. And the fact that the sandstone to the east borders on the lowest portions of the younger series (the lower tillite and the lowermost beds of the red-brown shale and sandstone) speaks in favour of this view. However, until closer investigations are made, this view cannot be adopted as proved fact.

In consistency with the view that the sandstone belongs to the older series, the conditions along the southern border of the sedimentary rocks may be explained in the following way: The vertical throw of the Varangerfjord fault decreases towards west and vanishes between Menavarre and Antebaktoivve; farther to the west the basal conglomerate of the older sandstone series rests on the peneplane.

II. Petrographic Description of the Erratics in the Tillites.

The geological conditions show quite distinctly that the land masses yielding the sediments were lying to the south. By studying the crystalline rocks of the erratics of the tillites it should be possible to define more closely the sources of the material, and perhaps also the direction of the movement of the glacier at different places.

However, since the crystalline area south of the sedimentary rocks has been very superficially investigated and rock specimens from it are few and occasionally collected, the tasks mentioned cannot be solved at the present time. Nevertheless, I shall give a summary description of the rocks — crystalline as well as sedimentary — which are met with in the tillite. The materials have been taken from different localities in the Tana and Varanger districts, and both from the lower and the upper tillite beds. In addition to my own collections I have used material collected by B. M. Keilhau, A. Dal, H. Rosendahl, O. Holtedahl. About 80 specimens have been examined.

Most of the specimens are quartz-dioritic in composition, some have the character of a fairly unaltered plutonic rock, some show gneissose structure. Also true granites are found. Further there occur greenstones, which probably for the most part are of hypabyssal origin.

As to the minerals, it is worth noting that amphibole has not been observed. Chlorite is derived from an original biotite in most rocks; only in one rock I have observed chlorite that probably developed at the cost of an amphibole, the only remaining vestige of which is the characteristic cleavage system.

1. *Granites and Granodiorites.*

Thin sections of 16 specimens. The rocks are of middle or coarse grain, they have the aspect of massive plutonic rocks. The colour is usually slightly reddish, in some cases intensely red. Signs of pressure action are common, the quartz having undulose extinction, the twin lamellae of the plagioclase being bent and some mortar structure being present.

Chief minerals: quartz, plagioclase, potash felspar, biotite (often chloritized). Subordinate: Chlorite, muscovite, apatite, zircon, spen, iron ore, calcite.

Quartz usually contains small inclusions of fresh biotite, apatite, zircon.

Potash felspar is characteristically microcline perthite, often containing grains of plagioclase, and very small grains of biotite, zircon and apatite.

Plagioclase (5—20 An) is usually present in greater amount than is the potash felspar. It is always somewhat sericitized. Myrmekite is often seen.

Biotite shows pleochroism: olive-green—light yellow, more rarely: brown—light yellow. It often contains inclusions of zircon (and spheⁿ?) surrounded by pleochroic haloes. It is never fresh, and frequently to a great extent replaced by chlorite (with pleochroisme green—yellowish, and anomalous blue interference colours).

In addition to chlorite manifestly formed from biotite, another chlorite, of a seemingly different mode of origin, occur in irregular patches. Its colour is purer green, and the birefringence lower, the interference colours are anomalous purple.

Small irregular spots of calcite may be seen. In specimens from Suorõejokka calcite, in veins and patches, occurs in rather great amounts. In this rock, calcite certainly has been introduced from the surrounding tillite matrix.

Some of the specimens examined differ from the general description:

1. Two specimens from the upper tillite, Skolvvejavrre (Varanger district), show porphyritic texture. Diameter of the phenocrysts (potash felspar) exceeds 1 cm, the size of the grains of the matrix averages 2 mm. The chief minerals are quartz, potash felspar, plagioclase; accessories are green biotite, zircon, apatite.

Microscopic examinations show potash felspar to be brownish, strongly corroded, surrounded by broad reaction rims consisting of myrmekite and muscovite, and intersected by joints containing plagioclase.

The plagioclase (15—20 An) is rather fresh. It has a narrow reaction rim of muscovite, and includes irregular patches of strongly corroded potash felspar surrounded by myrmekite. The structural features strongly suggest replacement of potash felspar by plagioclase.

2. In a coarse-grained, red granite (the lower tillite, Bigganjargga, on the Varangerfjord), plagioclase is entirely missing. The felspar is a micro perthite.

2. Quartz Diorites.

Thin sections of 18 specimens. The rocks are usually medium-grained, but also coarse-grained and fine-grained types occur. Colour grey or white. Granitic texture. Chief minerals: quartz, plagioclase biotite, (in part cloritized) and muscovite; subordinate: apatite, zircon

pyrites, magnetite, and aggregats of small grains of a brownish mineral.

Some grains of microcline are observed in three of the specimens.

The anorthite-contents of the plagioclase are 10—20 % (in one case below 10 %). The felspar is more or less altered to sericite.

Biotite is of olive-green colour.

The brownish mineral observed in some of the thin sections resembles rutile, it has high index of refraction and high birefringence; the grains are seen as small rods (size in mm 0.1×0.02) intermingled with green chlorite. The mineral is obviously secondarily formed.

One specimen (upper tillite, east of Maskejavrre) is entirely free from quartz. The rock is reddish, with irregular green spots. Grain size on an average 1 mm in diameter. The plagioclase (albite) is somewhat sericitized. The rock shows signs of cataclases, the albite lamellae being bent and the rock being intersected by veins containing crushed minerals and also new-formed minerals, as chlorite and epidote.

The chlorite is pleochroic green—colourless, interference colours brownish. Original mica does not seem to occur. A little apatite has been observed.

3. *Gneisses.*

Thin sections of 27 specimens. Medium-grained or fine-grained rocks. More or less distinct gneissose structure. Crystalloblastic texture.

Quartz and plagioclase are always the most common minerals. Biotite, chlorite, and muscovite are also plentiful. Potash felspar (microcline) occurs in 7 of the thin sections, more or less abundantly. Accessorily occur apatite, zircon, (?)sphen, magnetite, pyrites, garnet, tourmaline, zoisite-epidote, leucoxene, calcite, and (?)orthite.

Plagioclase is entirely fresh in some rocks, but usually it is more or less sericitized, so that in some thin sections the composition cannot be determined. The anorthite-contents are usually 10—20 %, in 5 cases below 10 %.

Biotite is brown in one rock, but as a rule olive-green. It may be fresh, but it is usually more or less chloritized.

Garnet has been observed in two thin sections.

Epidote and orthite are found in one of the garnet-bearing specimens.

Tourmaline occurs in one thin section.

Aggregates of a brownish mineral, as described above (p. 127) occur in several specimens.

A little calcite is observed in some thin sections. Partly it forms small irregular patches, partly it occurs in veins.

4. *Greenstones.*

Thin sections of 13 specimens. Probably for the greater part dyke rocks, perhaps in some cases altered lavas. The rocks are fine-grained or aphanitic. The colour is green or greyish-green. Strong alteration with formation of chlorite and carbonate is a common feature.

The chief minerals are plagioclase, chlorite, and calcite. A little quartz has been observed in 9 thin sections. Further epidote-zoisite, iron ore, apatite, brown biotite, muscovite, leucoxene and (?) rutile may occur.

Plagioclase is albite in 4 thin sections, for the rest (9 thin sections) the composition cannot be determined.

(?) Rutile: Aggregates of small rod-like minerals, which have high index of refraction and high birefringence. Parallel extinction. Green chlorite between the rods.

5. *Sedimentary rocks.*

Concerning the pieces of sandstone it can only be said that they may very well have been derived from the older sandstone series, but they may just as well have come from the Raipas series. As illustrations, two specimens will be described:

1. White sandstone. Dolomitic tillite, the west side of the Tarmfjord. Quartz is the dominant constituent. Rounded grains, diameter 0.15—0.75 mm. In addition a few grains of zircon. The cement is chiefly calcite.

2. Fine-grained, slightly reddish, quartzitic sandstone. The lower tillite, SE of the head of the Smalfjord. Main constituent quartz; rounded grains. Microcline and plagioclase, both fresh, are well represented. Some grains of zircon and of muscovite are also present. The cement is chiefly silica, but also a little iron ore. The grain size falls into two groups; most of the grains are 0.2—0.3 mm in diameter, the others 0.5—0.7 mm.

Different types of dolomite rocks have been mentioned before (p. 80). They may have come from the older sandstone series, or they may have belonged to the Raipas series.

Two of the examined samples differ from the general types, and will be especially described:

1. Heavy, brown-violet and rusty, somewhat porous rock, megascopically resembling a slaggy lava. In part oolitic structure. The basal beds of the lower tillite, west side of the Tarmfjord.

It appears to be a carbonate rock, perhaps sideritic in composition. All indices of the minerals are greater than that of canada balsam. The grains are partly yellow, the stain beginning along the selvages. In the oölites the size of the crystals is 0.1–0.15 mm in diameter, in the matrix the diameter is below 0.05 mm.

2. Greyish green, very fine-grained rock, megascopically resembling diabase. Locality as above. Chief constituent carbonate, often somewhat yellowish, possibly siderite in part. Further there occur small angular grains of quartz (diameter about 0.05 mm), some laths of muscovite, green chlorite, and crystals of pyrites. Megascopically no stratification can be seen, but with the microscope a certain parallel arrangement is observed.

Discussion.

The available rock specimens from the crystalline area south of the tillites is quite insufficient to give any certain data as to the sources of the erratics and the direction of the glacier movement. Only this can be said: South of the sediment border there exist rocks resembling the quartz dioritic and the granitic rocks of the tillites. According to O. Høltedahl (1918, p. 212), there occurs, between the sediment border and the Tana River, along Lævvajokka and eastwards, a belt of light-coloured, highly garnetiferous rocks, partly quartzitic, partly granitic. This belt, 30–40 km broad, trending NNW, is directly connected with the granulite area of Finland. Farther east occur granitic rocks, gneissose rocks, and also hornblende schists, and hornblende gneisses. The rocks of the area south of the Varangerfjord consist mainly of gneisses and granites.

I have examined thin sections of the rocks resembling those of the erratics, and a brief account will be given here.

Locality Karibotn, south of the head of the Varangerfjord. Three thin sections of granodioritic or quartz dioritic gneisses.

Chief minerals: quartz, acid plagioclase, biotite (brownish olive-green), and also microcline. Accessories: apatite, zircon, reddish garnet, and a little zoisite-epidote. Plagioclase is usually slightly sericitized, biotite a little chloritized.

Several erratics in the tillites might have been derived from here.

Two thin sections of dyke rocks have been examined. One (locality: Braselv, South Varanger) consists of quartz, epidote, chlorite, and ilmenite which in part has been changed to leucoxene. The other (from Spikargaissa, south of Karlbotn) consists of plagioclase, pyroxene, ilmenite, leucoxene, and a green mineral which obviously is amphibole and not chlorite.

In the tillite material I have found no rocks like these.

Holtedahl has collected some gneiss specimens at Gollevarre (east of the Tana River, south of Skipagurra). The chief minerals are quartz, acid plagioclase, biotite (brownish olive-green); zoisite-epidote in varying amounts, further apatite and a little pyrites.

Epidote-bearing rocks are not common among the erratics of the tillites.

A gneiss from Aleknjarg (south of Skipagurra) contains quartz, plagioclase, biotite (dark olive-green), zircon, apatite, muscovite. It thus resembles the gneisses of the tillites.

I have collected a few specimens of gneisses and quartz diorites south of the sediment border in the Čikkejok district. The minerals are the usual: quartz, acid plagioclase, biotite, chlorite, a little muscovite, apatite, and also in some cases zoisite-epidote.

Amphibole has not been encountered in any of the quartz diorites and gneisses thus far described. In the Čikkejok district, however, amphibole-bearing rocks are common (p. 115). Also from other places amphibolites and hornblende gneisses have been observed. No such rocks have been found among the erratics.

Reference could be made to the fact that garnet is a chief constituent in some of the sandstones between the tillite beds, and of the sandstone below the lower tillite in the Čikkejok distrikt (p. 84). Thus the source of material of these sandstones must have been rocks rich in garnet; it is natural to think of the light-coloured garnetiferous rocks which are mentioned by Holtedahl from the area east of Lævvajokka. But in the tillites these rocks are not represented.

The direction of the glacial striae on the substratum of the Bigganjargga-tillite (at the head of the Varangerfjord) is perhaps

merely a local phenomenon, giving no information of the general direction of the ice movement. According to H. Reusch (1891) there are at Bigganjargga two sets of striae, one set with the direction SE—NW, and another, fainter, set with the direction E—W. It must be assumed that the movement here was from SE towards NW, that is away from the present-day sea, for it is impossible that the ice can have come from a northerly area. Obviously the movement corresponding to the older set of stria must have been from east to west, and not the opposite.

III. General View of the Sandstone Divisions of Finnmark.

A. Eastern Finnmark.

1. *The Older Sandstone Series.*

The older series is completely of shallow-water origin, in the sandstone ripple marks occur, in the shale, mudcracks and patches of clay material. Current bedding of greater and smaller dimensions are also observed. Real conglomerates are, however, not common; in the sequence of Tananes there is only one horizon.

The dolomites are also shallow-water deposits. According to Holtedahl (1918, p. 261), mudcracks and ripple marks are especially common in the dolomite-shale-sandstone series on the north coast of the Varanger Peninsula, and intraformational conglomerates or breccias are common there as well as in the Trollfjord and Porsanger dolomite.

In spite of current bedding and conglomerate layers the sediments have not the character of river sediment; especially the occurrence of dolomite contributes to this view. We must suppose that the sedimentation has taken place near the land, and that the supply of material has been abundant. There must have been, in any case at certain times, perceptible currents in the water.

Whence the material derives, or, in other words, where the land masses yielding the sediments were situated, is difficult to say with certainty. The clastic minerals are quartz, plagioclase, mica, chlorite, microcline, zircon and tourmaline; in short, the common minerals in any gneiss area. Thus the contents of minerals are no obstacle to the material being derived from the crystalline rock in the south.

2. *The Unconformity.*

From my studies in these areas, I must fully agree with Holte-dahl's supposition that prior to the sedimentation of the younger series, a down-faulting has taken place on a line along the Varangerfjord and further westwards. Directly to verify this down-faulting can hardly be done. Traces of fault-breccias are not observed, nor could it be expected. We must remember that the border is covered by the younger sandstone, and, further, there are great masses of loose material in the areas along the border.

This sudden disappearance of the older series in the south might also be explained in another manner, viz., by assuming that during the deposition of this series the surface of the crystalline rocks was sloping rather steeply towards north. A reason against this is the lack of coarse material in the older series; anyway, one might well expect the rocks near the crystalline area to distinguish themselves from the rocks farther north. That is not the case, however, the rocks of the Klubb fjell series on the Varangerfjord being of the same character as those of the Tananes series.

I do not think too much weight, however, can be given such a negative proof. On the contrary, more importance might be attached to the obvious fact that the younger series lies unconformably on the older, thus some movement must have taken place at that time. The block in the south is relatively elevated, and we know that during the deposition of the younger series, real terrestrial conditions existed south of the present sediment border. It appears clearly from the geological conditions that the material of the tillites and the interjacent shale-sandstone series has been brought from there.

But also the block in the north seems to have been exposed to erosion which has caused the unconformity between the older series and the younger. In the Tanafjord district the direction of the greatest angle seems to be N 30° à 40° E; on the Varangerfjord, towards east, even younger layers are seen below the plane of unconformity. The angle of unconformity is, however, very small in the Tana district, max. 2°, but at a length of, say 10 km, 2° would cause a difference in the sequence of 350 m.

The vertical throw of the fault seems to have been greatest in the east, as eastwards we find still younger beds of the Klubb fjell series, and, as westwards, the surface of the crystalline area gradually grows more even.

The supposition that the uneven surface of the crystalline area has been formed by erosion after the formation of the older sandstone series, involves that all sedimentary rocks in the depressions south of the fault-line must be classed among the younger series, thus also the glaciated sandstone below the Bigganjargga tillite on the Varangerfjord.

Also in the Čikkojok district sediments below the lower tillite have been dealt with, viz., those on the hills "176" and "204". On the latter, the material has been deposited in a distinct depression, and must be reckoned in the younger series. The rock is an arkose, the minerals are angular and fresh, suggesting glacial or arid climate, in this case obviously glacial.

3. *The Younger Sandstone Series.*

The lower tillite. The occurrence of the tillites as two extended layers in a series of sandstones and shales, and the common presence of a more or less well-developed stratification, tell of a deposition in water; probably the material has dropped from drifting icebergs. As regards the lower tillite, the occurrence at one and the same place, of different types of the tillite, in part with well marked borders, possibly suggests that there has been more than one advance of the ice mass.

Outermost on the peninsula west of the Smalfjord, the ice mass, alternatively, the base of floating icebergs, has eroded the Vagge shale. The deposition of the dolomitic tillite has followed just afterwards, the excavated material and the lowermost part of the tillite being somewhat mixed. The coarse stratification of the dolomitic tillite indicates a glacifluvial deposition. Portions of stratified fine mudstone, containing some straggling erratics and layers of gravel, show that the deposition has taken place in water. I should be inclined to think that the front of the glacier was situated near the head of the present fjord at a time when the glacier was eroding mainly dolomitic rock.

The decrease of the dolomitic tillite towards the south may, however, also be due to ice erosion of the moraine during a later advance of the glacier. The largest thickness of the lower tillite — about 45 m — has been measured at the head of the Smalfjord. Farther south, the thickness seems to be far less, this being due to less deposition of material or to temporary periods of erosion of the

bottom moraine. At the southern border of the sediments the thickness is again larger, being at least 20 m. Of interest is the fact that the block material there consists exclusively of crystalline rocks. It suggests that the tillite is there a shade younger than that of the Tanafjord, the erosion of the glacier having reached the crystalline basement. However, at that time some parts of the present Pre-Cambrian crystalline rocks must still have been covered by sedimentary rocks, as we find erratics of sedimentary rocks in the upper tillite. Possibly, the remaining parts of these rocks were farther away, and the glacier at the time of the formation of the Čikkojok tillite had a comparatively little extension.

The tillite in the Čikkojok district differs in colour from that of the districts farther north, and also from that of Bigganjargga on the Varangerfjord. Also this fact indicates that the Čikkojok tillite and the Tanafjord tillite are not quite contemporaneous deposits, no reason being present for a horizontal variation in colour of the tillite, if the material had dropped down at the same time everywhere.

Peculiar features of the tillite at Vaddasbakke is the occurrence exclusively of sandstones as erratics, and the rounded shape of some of them.

Southwards from Vaddasbakke the number of erratics decreases, and possibly vanishes near the Antebaktoaivve mountain. It may have some connection with the dying out of the fault towards the west.

Above the Bigganjargga tillite on the Varangerfjord, there occurs light-coloured sandstone with irregular beds of badly assorted conglomerates, especially containing dolomite pebbles. Holtedahl regards this as glaci-fluvial material. Close above the lower tillite there are, also in the Čikkojok district, sediments, which are not found farther north, viz. a zone of shale and sandstone, about 50 m in thickness. This material has consequently been deposited only near the land.

The red-brown shale and sandstone has thus a somewhat varying substratum: On the Tanafjord, the lower tillite, on Čikkojok and on the Varangerfjord, the rocks just mentioned, and between the Varangerfjord and Lismajavrre, basal conglomerate directly on the uneven surface on the crystalline rocks.

During the deposition of this stage, the climate has obviously been milder, so that any glaciers have not reached the sea. The period should be considered as an interglacial one. However, as the

minerals are fresh and little rounded, frost has probably still been a very active agent in breaking down the rocks.

When we are comparing the character of the rocks at different places, it seems obvious that the sediment-yielding land was lying to the south. Near the southern border of the sediments, coarse sandstones, partly in very thick beds, predominate, but farther north the shale material is present in about equal amount as the sand.

The exact measurement of this stage is most often impossible. In the Vestertana—Njukōagaissa districts the thickness is between 200 m and 400 m, from there it decreases in any case towards east and north-east, being at Lavvonjargga and east of Tana Church only about 100 m. Sandstone beds are practically missing in the two last-mentioned places. East of Leirpollen, the thickness seems to be very slight. According to Holtedahl (1918, p. 169), the measurement of this stage is also very difficult on the Varangerfjord. He estimates the thickness in the western part of the Nesseby district to near 100 m, whilst eastwards, in the Mortensnes—Per-Larsavik districts, the thickness greatly varies in short distances, probably chiefly on account of tectonical disturbances. Just east of the houses at Mortensnes, the thickness of the sediments between the dolomite conglomerate and the red tillite is more than 50 m, whilst east of Per-Larsavik, the corresponding thickness is only about 5 m.

Even if secondary causes may play a great part, I do not consider it very probable that a thick stage consisting of such coarse beds as those known from the Čikkajok district, can be pressed out to nearly nothing without the rocks, on the whole, having become more metamorphic than is the case. I should therefore think that the thickness, also eastwards, has originally been less.

To the north, between the Trollfjord and Gressdalen, I have made no measurement of the stage, owing to short time, but it should be possible there. I got the impression that the thickness was there less than in the Vestertana—Njukōagaissa districts. We shall notice that there is less shale proportionate to sandstone at Grasdalen than there is at Vestertana and farther south.

The upper tillite has a more uniform character than the lower tillite, and the variation of the thickness is more even.

The shale fragments in the upper tillite resemble the shale of the stage between the tillites; probably the new glacier has in places, perhaps chiefly near the land, eroded the unconsolidated sediments.

That only clods of clay and not of sand are found, is natural, just when the sediments were unconsolidated, as the sand will break up, while the cohesion in the clay will be so great that the material remains in clods.

As to the colour of the upper tillite, it is red-brown near the sediment border, and grey-green farther north. At Seida, and west of Maskejavrre, the lower part is red-brown, the upper part is grey-green. The red-coloured part of the tillite is consequently a lower part, disappearing towards the north.

The variation in the thickness of the upper tillite is shown on the map Fig. 42. The figures are taken from places where at the same time underlying and overlying beds are seen. The figures must not be taken too literally, as I have in most cases not directly measured the thicknesses. But the differences in thickness are so conspicuous that there is sufficient basis for a judgment of the direction of the variation.

The thickness of the tillite west of Maskejavrre and in the Njukêagaissa—Vestertana districts is about the same, and rather great, so that the tillite ridges form a prominent feature of the landscape. Westwards from Njukêagaissa the thickness distinctly decreases. Also towards the NE, the thickness decreases, this can be seen already at Vestertana, and is quite distinct at Stappogiedde. On the Trollfjord, the thickness, at any rate, is not greater than at Stappogiedde. Peculiar is the great amount of carbonate in the upper tillite of the Trollfjord.

Between Njukêagaissa and the Tana River it is difficult to settle the variation of the thickness; but when going as far east as to Leirpollen, the thickness is found to have decreased considerably. However, by then we have also moved a good deal towards the north.

At Seida the thickness apparently belongs to the greater group. In the environment of Skipagurra, and westwards along the Varangerfjord, there are no determinations of the thickness from places where overlying beds are exposed.

Conclusions concerning the original thicknesses of the tillites must be drawn cautiously, as icebergs may have eroded the previously deposited morainic material. There is, however, hardly any reason to question an original decrease of the thickness of the upper tillite westwards and north-eastwards from Njukêagaissa.

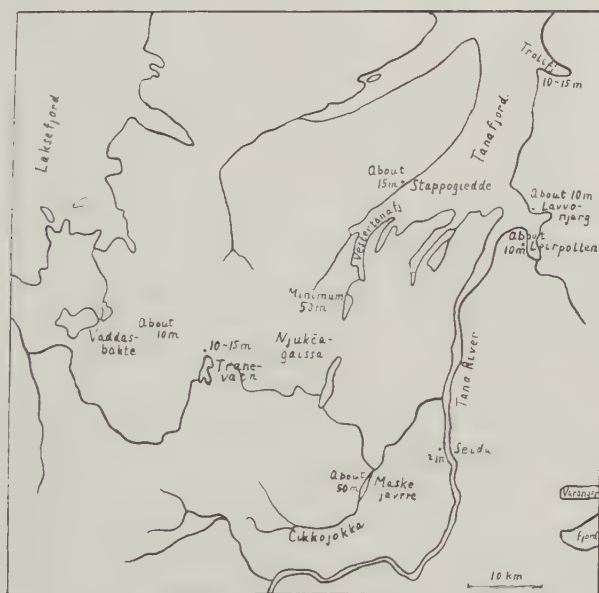


Fig. 42. The thickness of the upper tillite.

As regards the red-brown shale and sandstone, and also the upper tillite, one has the impression that an especially rich supply of material has taken place in the Čikkajok—Lismavarre district, and that the material has spread fanwise. In the Čikkajok district we have also seen a locally occurring zone of sediments just above the lower tillite.

The sediments above the upper tillite. This part of the sequence gives us no hints as to the origin of the material. I have mentioned (p. 87) that as regards the lower stages — that of the bluish-green shale and that of the red quartzitic sandstones — the development in the north-western districts seems to differ from that of the south-eastern. In the latter district also the thickness of the bluish-green shale seems to be greater than in the former, but I cannot say with certainty.

The probability is that the source of the material was the same land as that which produced the tillite material. The equal-grained and small-grained character of the red quartzite may perhaps indicate wind-blown material, though it must have been deposited in water. The frequently occurring ripple marks of the sandstone beds show that deposition has, moreover, taken place in shallow waters.

No stratigraphical break has been observed; on the contrary, there always seems to be transitions between the stages I have separated. This is the case also further up the huge stage of light coloured sandstone at Duolbasgaissa. Nor does the conglomerate seem, as it appears on Boksjokka, to represent any break in the deposition.

4. *The Fossiliferous Stage and the Hyolithus Zone.*

The fossils on the Digermul Peninsula are, according to Strand, of Middle Cambrian, perhaps Upper Cambrian, age; consequently, the rocks are younger than the Hyolithus zone of Western Finnmark. The mode of occurrence of the fossils, as also the fact that *Lingulella* is found in a series of several tens of meters, indicates a rapid sedimentation. The lowest beds — 30 à 40 m at most — are unfossiliferous, but, on account of the rapid sedimentation, it is improbable that these beds correspond to the Hyolithus zone. Then the question suggests itself whether any part of the sequence at Stappogiedde corresponds to the Hyolithus zone (the tillite being considered older than fossiliferous Lower-Cambrian). As previously mentioned, there is only very little chance of finding fossils in the rocks of the Stappogiedde sequence, the only possibility left being that a correspondence can be traced by the petrographical character.

Holtedahl has dealt with the Hyolithus zone on the Alta River and south of the Porsangerfjord. The Hyolithus zone everywhere rests on the peneplane above the Pre-Cambrian crystalline rocks. The thickness varies somewhat, from 150 m to 230 m; but this fact has little importance as the zone is separated by a thrust plane from the overlying rocks — metamorphic rocks or Porsanger sandstones. The sequence in the Alta district is, broadly speaking, the following (for an exact division, see Holtedahl, 1918, pp. 28—34 and pp. 216—221): Above coarsely clastic basal zone with conglomerate and sandstones, there comes a zone of green and chocolate-brown shale, arenaceous higher up, containing numerous sandstone beds. Thereupon an about 20 m thick compact sandstone occurs, then again a more argillaceous zone, which, however, has not little admixture of thin sandstone beds; the shale is usually yellowish or reddish.

In the Gaggagaissa mountain (south of the Porsangerfjord) the about 20 m thick sandstone is missing. The *Platysolenites* level, which between Torneträsk (Sweden) and Finnmark lies below 100 m,

in the Gaissas lies at about 120 m, that is suggesting an increase of the thickness from SW towards NE.

The only part of the Stappogiedde sequence which, from the character of the rocks may be considered as an equivalent to the Hyolithus zone, is the thick shale stage above the red quartzitic sandstones. There is, however, no actual correspondence with the Hyolithus zone as I know it from Hortedahl's description. Shallow-water deposits, however, may vary rather rapidly from place to place, and, possibly, in the Tana district we have to do with sediments deposited nearer land than those in West Finnmark, on account of the difference in the previous history of the areas. I am especially thinking of the fault in the direction of the Varangerfjord, which has, in any case for some time, caused a real highland to the south.

Frankly speaking, it is still an open question whether some part of the sediments of the Digermul Peninsula corresponds to the Hyolithus zone, or whether in the Tana district a stratigraphical hiatus exists, the Hyolithus zone never having been deposited. Detailed investigations on the Digermul Peninsula may possibly clear up the matter.

B. The Porsanger District.

It is still impossible with full certainty to state the relation between the Porsanger series and the sequence of the Tana district; but everything tends to the conclusion that Hortedahl's view is correct, viz. that the Porsanger series corresponds to the older sandstone series of the Tana district.

The lower part is a sandstone series of considerable thickness, in the upper part of which a dark shale zone is seen. In 1934 I visited the upper part of the Porsangerfjord, to me the sequence looked like the upper light-coloured quartzitic sandstone with the Vagge-shale on the east side of the Tanafjord. Above the light-coloured sandstone at Porsanger there comes a succession of shale and sandstone, well interbedded. The sandstone is mostly greenish, the shale mostly red-brown, but also black, green, yellowish. Above this, the Porsanger dolomite, whose light-coloured, often barren, rounded crags are very conspicuous.

To the shale-sandstone stage and the dolomite we have, as mentioned by Hortedahl, probably an equivalent south of the Troll-

fjord, in the shale zones with dolomite, which occur between the Vagge-quartzite and the lower tillite. However, there the whole is of far smaller dimensions. The dolomite-shale stage, however, may originally have been of greater thickness, having probably been exposed to erosion prior to the deposition of the tillite. I have in the next chapter suggested the possibility that the dolomites on the north side of the Varanger Peninsula belong to the same horizon. Also the great quantity of dolomite in the tillites, especially in the lower tillite on the peninsulas at the head of the Tanafjord, suggests that the Porsanger dolomite belongs to the older series. In the tillite dolomite fragments are often seen with structures which are common in the Porsanger dolomite, viz., breccia-dolomite, oöides, and stromatolites. Actual oörites are also known from the tillites, they are not observed in the Porsanger-dolomite. The contents of dolomite in the tillite cannot, however, be considered as a final proof for the Porsanger-dolomite as belonging to the older series, as the dolomite might be derived from the Raipas division. I would not now enter upon a thorough discussion of the relations between the Porsanger-series and the series of the Tanafjord, the solution will not be reached until investigations are made in the areas between the head of the Laksefjord and Porsanger.

C. The Alta District.

1. *The Raipas Series.*

The Raipas series has been subjected to folding movements with subsequent denudation before the deposition of the tillite-bearing Bossekop series commenced. The unconformity between them is thus of a higher grade than that between the older and the younger series in the Tanafjord and the Varangerfjord districts. It does not seem very probable that the movements which to the east have caused the slight tilting of the older series, should be contemporary with the real orogenesis whereby the Raipas series was folded. The Raipas series is also distinguished from the other sandstone series in Finnmark in its contents of volcanic matter. I consider the Raipas series to be older than the older sandstone series of East Finnmark.

Holtedahl (1918, p. 227) quotes that N. Zensén and Th. Vogt regarded as probable a Pre-Cambrian age of the Raipas-series, because a well-marked folding, older than a sedimentary sequence

which is again Pre-Caledonian, most naturally had to be classed as Pre-Cambrian. Holtedahl states on the same page (in translation): "That there is a considerable interval of time between the forming of those two series¹ is therefore beyond doubt. With the supposition of the Bossekop series as Lower-Cambrian we must in any case go the whole length and consider Raipas as belonging to Pre-Cambrian."

Holtedahl was at that time of the opinion that the Raipas series was equivalent to the strata on the north side of the Varanger Peninsula, which strata he regarded as a younger sub-division of the older sandstone series of the Tanafjord, but which were missing on the Tanafjord on account of erosion prior to the deposition of the tillite. We must now think it probable that the sedimentary rocks on the north side of the Varanger Peninsula corresponds to the series of Tananes; thus I could suggest as a possibility that the Kongsfjord shale is equivalent to the Stangenes shale, and that the dolomite-shale-sandstone stage of Båsfjord, Syltefjord and Persfjord, is a continuation of the dolomite-shale stage of Trollfjord. It is natural that the thickness of the dolomite-shale stage is greater at Båsfjord etc., than at Trollfjord, as, on account on the unconformity, we should find younger beds of the older series the more we get towards the NE.

In any case, there is now no reason to regard the Raipas series as equivalent to any part the rocks of the Varanger Peninsula. And the consequence of the altered view of the age of the tillite, viz., from Ordovician to Eo-Cambrian, will, therefore, according to Holtedahl himself, be that the Raipas series belongs to Pre-Cambrian.

However, to state this as an absolute fact may be going too far; it is difficult to say what time would be required for the petrification of the sediments, folding and subsequent denudation. Consequently, there is no absolute reason for making a distinction of systems on account of such an unconformity.

2. *The Bossekop Series.*

It should be beyond doubt that the tillite of the Bossekop series corresponds to one of the tillites in the Tana—Varangerfjord districts, but to say which of them is hardly possible. The red shales and sandstones above the tillite give no reasons in this respect. Nor can

¹ The Raipas series and the Bossekop series.

it be determined whether the light-coloured, about 110 m thick, sandstone series below the tillite belongs to the older or to the younger series of the Tanafjord. The occurrence in the tillite of erratics very like types of the underlying Bossekop quartzite might indicate that there exists below the tillite a break in the succession, as on the Tanafjord.

The position of the tillite in the sequence is, according to Holte-dahl's description, entirely conformable and no striation of the substratum has been seen.

IV. Some Remarks on the Eo-Cambrian Glaciation.

O. Kulling (1934) gives in his treatise "The 'Hecla Hoek Formation' round Hinlopenstredet" a general view of all the known occurrences of tillites at the base of the Cambrien or just before it. The general view is accompanied by a valuable, up-to-date, bibliography.¹ He graduates the occurrences into three groups (p. 245):

I. "Those which are conformably underlying fossiliferous Cambrian": Spitzbergen, East Greenland, Finnmark (and The Fisher's Peninsula of Finland-Russia), South Norway, China, Australia, North America (Salt Lake in Utah).

II. "Those which are unconformably overlain by Cambrian sediments": Central Siberia and Central Asia (three occurrences, at a great distance from each other).

III. "Those which, though the absence of fossils precludes any definite determination of their age in relation to the oldest Palaeozoic, are considered contemporary with any of the first group": North India, South Africa, Central Africa.

Especially closely he deals with the relative geological position of the correlated districts round the present Scandic.

To Kulling's perspicuous and critical view I will only add some points of interest for the correlation. Firstly, the find of fossils on the Digermul Peninsula finally proves that the tillites of Finnmark belong to Kulling's group I. Secondly, I would point to the interesting

¹ To this is now added: Edgeworth-David, Sir T. W. Memoir on Fossils of the Late Pre-Cambrian (Newer Proterozoic) from the Adelaide Series, South Australia. Sydney 1936.

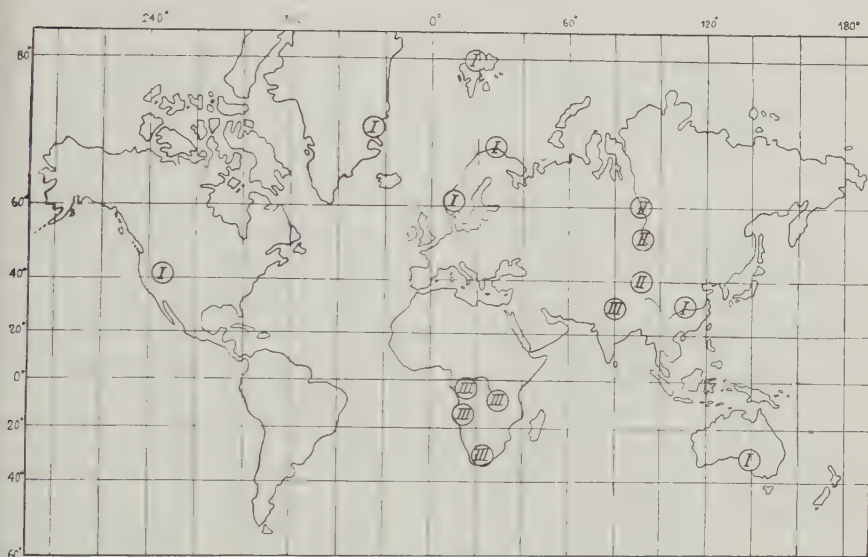


Fig. 43.

fact that both in East Greenland and in East Finnmark there are two tillite horizons, separated by a zone of sandstone and shale, which must be considered to be interglacial. Further, a common feature of the two areas mentioned is the greater amount of dolomite in the lower tillite than in the upper one, which contains comparatively more of crystalline rocks. This indicates an erosion of an older part of the sediment formation, which erosion has gradually advanced into the crystalline basement.

As regards the block material in the tillites, Kulling has demonstrated accordance for some eruptive rocks in the Sveanor tillite (Spitzbergen) and the upper bed of the Cape Oswald tillite (East Greenland); he concludes (1934, p. 243): "It is rather likely that some land existed between East Greenland and the Spitzbergen districts — a geanticline between the shallow geosynclinal basins — supplied the material for the Sveanor and the Cape Oswald tillites." The rocks in question are chiefly hypabyssic or surface volcanic, which, he presumes, have erupted just before the time of the glaciation, but after the deposition of the elder part of the formation.

In the tillites of Finnmark, gneisses and granites are the most frequent crystalline rocks, whilst intrusives or extrusives are rare.

And, even if some of the greenstones should be very like rocks found in the Sveanor or Cape Oswald tillites, and we also presume that the distance between Greenland and Norway was in those days shorter than now, it seems very little probable that the tillites of Finnmark had the same sediment-producing area as the Sveanor and the Cape Oswald tillites, — on account of the geological conditions, the material of the Finnmark tillites having been brought from the south.

To the occurrences of tillites on Spitzbergen which are mentioned by Kulling, the locality Gåshamna, Hornsund, might be added. Members of the expedition of Hoel and Røvig, 1917, collected specimens there of an unassorted conglomerate, the specimens being now in the Geological Museum, Oslo. The groundmass of the rock is a bluish quartzite, with rounded quartz grains of size above 1 mm in diameter, the fragments consist of dolomite with oolitic structure.

On The Fisher's Peninsula, North Finland, there are no fossiliferous rocks, and the reason why the tillite has been reckoned to the class I is exclusively the short distance from Finnmark. K. Lupander (1934) has given a summary of the sedimentary rocks on the Finnish part of the peninsula. In these sedimentary rocks there occur a conglomeratic sandstone or arkose, and a shale with angular fragments, both are supposed to be moraine conglomerates. The total thickness is nearly 1500 m. The other rocks to some extent resemble the sedimentary rocks in East Finnmark; but any correlation between the sequences is not possible.

Lupander has found glauconite in a considerable part of the sequence; this mineral has not been found in the series of Finnmark.

The border line between the sediments and the crystalline rocks seems to be a continuance of the fault line along the Varangerfjord.

Holtedahl has in several papers mentioned the tillite-like character of the unassorted conglomerate (the Moelv conglomerate) in the Eo-Cambrian sparagmite of Southern Norway. Striated boulders have not been found, but there should hardly be any doubt about the glacial origin of the conglomerate. The occurrence of an unassorted conglomerate whose character and stratigraphical position are to such an extent consonant with the tillites of Finnmark, East Greenland and Spitzbergen cannot reasonably be explained in another way.

V. The Caledonian Deformation in Eastern Finnmark.

1. *The Effects of the Pressure on the Different Parts of the Series of Strata.*

In the introduction I pointed out that I have studied the tectonical conditions in the area only in connection with the investigation of the stratigraphy. As the observations are thus comparatively occasional, I will not engage in a thorough discussion of the tectonics, but only point out some of the more conspicuous features.

The Tana district is very suitable for studies of the effects of horizontal forces on a series of strata with beds of different resisting power. The solid, rigid, though brittle sandstones react against the pressure in a manner different from that of the weak shales. A horizontal bed can be folded on account of horizontal compression only when the bed has sufficient strength to lift the overlying beds in the anticline and to press away the underlying beds in the synclines. Willis, B. & Willis, R. (1934, p. 77) call such beds competent, whilst weak beds as shales are called incompetent; in the latter the stress is released by the crumbling of the rocks and by the forming of numerous shear planes. Over a longer distance, the pressure will be transmitted by the competent strata, thus controlling the folding, whilst the incompetent strata are laid in passive folds.

The older sandstone series has, broadly speaking, acted as a competent unit; on Tananes and at Stangenes Vagge, the whole series — about 1000 m — takes part in the forming of one fold. The thickness of the shale zones, which are in themselves incompetent strata, is not large enough to separate the series into more groups of competent beds, the zones, however, in a number of cases cause irregularities in the attitude of strata. At the folding, the rigid strata move relatively, chiefly in the way that each bed moves up the flanks of the anticlines proportionate to the underlying beds. Shale beds between the sandstones facilitate the movement. In the arenaceous shales rich in thin-splitting sandstones, this movement takes place along the bedding planes, whilst in the more homogeneous shales, like the Stangenes slate, a secondary schistosity is produced. With strong deformation the shale zones may be highly pressed out, e. g., SE of Vagge, where the shale zones towards SE are gradually growing indistinguishable.



Fig. 44. Oblique folds of the upper tillite.

The huge folds are always more or less oblique, the axial plane dipping WNW or NW. The anticlines are often overturned, then the brittle sandstone beds will often break, and at further development the folds may pass into thrust faults, e. g., SW of Gavesluft on Tananes and at Lavvonjargga.

The lower tillite tectonically follows its substratum, the older sandstone series. But it is a more yielding bed, which may lie in more acute folds without having broken, the deformation force having been released by movements along shear planes which are the cause of the frequent schistosity of the tillite. The dip of the schistosity planes is about 70° , more or less WNW. The degree of schistosity depends on the local deformation, and thus varies from place to place.

The tillite is more resistant against weathering than are the brittle sandstones. As long as an anticline is covered by a cap of tillite it can remain as a ridge, but as soon as the tillite has been penetrated, the further development of the valley seems to proceed rapidly; it may be seen very well on the peninsulas between the Smalfjord and the Tarmfjord. Generally, the valleys and fjords in the Tana district are mostly developed along anticlines.

The upper tillite is the competent bed proportionate to its adjacent strata; it has formed its folds independent of the older sandstone series, except where the latter has domed highly, as at Niukõagaissa. The folds are always inclined, most often overturned, and not seldom the upper part of the anticline has been somewhat thrust towards SE or ESE over the substrata so that a discordance appears, giving the impression of imbricate structure. This impression is intensified by the fact that the front of the anticline has in many cases been removed, so that in going towards WNW, we repeatedly see tillite lying over the red and brown shale and sandstone (Fig. 44). Secondary schistosity, with dip at about 70° , is more frequently and distinctly developed than in the lower tillite.

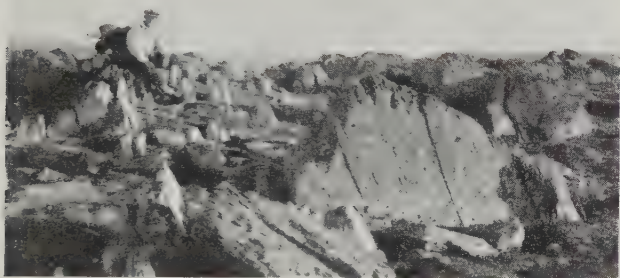


Fig. 45. Schistosity of the upper tillite. West of the Njukāgaissa mountain. Seen from NNE.

The stage "red and brown shale and sandstone" is, taken as a whole, an incompetent unit, but, in itself, consists of strong sandstones and weak shales in rapid alternation. The result is a very intensive folding, the folds are most often acute and isoclinal. Only very seldom these strata do appear approximately flat-lying and undisturbed. This is the case at the Alteberg peninsula, but even there it may be seen how the sandstone beds form unexpected and irregular folds. The mud-rocks in this stage have a distinct schistosity, in part coincident with the bedding, but also often deviating from it.

The stage "dark shale and coarse sandstone" above the upper tillite reacts against the compressive force like the stage between the tillites.

Farther up the series, the following strata are incompetent: The red-violet shale and the bluish-green shale, the 550 m thick green siltstone, and the fossiliferous shale stage. Only where the adjacent competent beds are strongly folded, has a comparatively intensive folding of these beds taken place; for the rest the horizontal compressive stress has been released in forming shear planes, thus producing schistosity. The degree of the schistosity varies about proportionately to the intensity of the folding of the competent beds at the different places. The fossiliferous shale splits along the bedding planes, as I have previously mentioned (p. 109).

On the other hand, competent strata are the following: The red quartzitic sandstone, the neighbouring white sandstones, and the thick Duolbasgaissa sandstone stage. Seen from the Tanafjord, the

last-mentioned is apparently lying fairly flat and undisturbed, as the mountain side and the direction of the strike are coincident. The beds dip more or less towards NW, and in the small valley-cuts, traces of strong tectonic disturbances happen to occur. Thus the photo. (Fig. 46) shows a peculiar tectonic discordance, probably formed by the total squeezing up of a syncline and the subsequent thrusting of the upper part of the strata (locality: about 2 km SW of Duolbasgaissa).

Shortly summarizing, I can say that the deforming force seems to be of equal strength in all parts of the series, but the character of the deformation and the degree of the folding, depend on the character of the rocks, and then not only that of the strata in question, but also of the adjacent strata.

It might be expected that the deformations were stronger in the north-western than in the south-eastern districts. In order to clear up that question, corresponding strata must be used for the comparison, or, in any case, the type of the rocks must be considered. I cannot state anything with certainty in this respect, but there are at any rate no conspicuous difference, and no continuous variation.

2. Direct and Indirect Folding.

When a flat-lying series of strata is affected by a horizontal force, the compression will result in a folding which successively is transmitted in the direction of the force. The folding axes are developed at right angles to the force, the folds are long and regular; and the folds lie closely together, as a greater part of the force cannot be transmitted to the area below a fold until the fold has been closed and thus acts as a block. The axis plane of the eventual, unsymmetric folds will all dip the same way, against the direction of the force. Willis, B. & Willis, R. (1934, p. 94) call this sort of folding *direct folding*. *Indirect folding* is due to a force couple acting in the horizontal plane, causing a rotational stress in the area. One diagonal in the shearing rhomb will be lengthened, the other shortened, the folds are developed at an angle of 45° to the forces. The folds may be developed at any place in the area, thus being irregular and distributed unequally.

A third case is the combined effect of direct and indirect folding.

The folds in the Tana district are practically always inclined. As all of the axis planes dip the same way, towards WNW or NW, a direct compression must have taken place. The inclination of the folds is due to a rotational stress in a vertical plane, produced by the friction which rises because

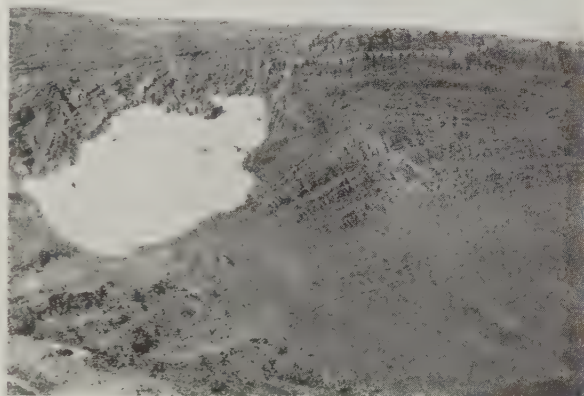


Fig. 46. Tectonic disconformity. SW of Duolbasgaissa.

the deformation reaches only a certain depth in the series of strata.

There are, however, good reasons for assuming that direct compression is not the only deforming force, but that the deformation in a rather greater degree is due to a couple of forces in the horizontal plane. Primarily, the irregularity of the folds must be pointed out. Very often a fold is at one place prominently developed, but some kilometres away along the trend it is rather inconsiderable, whilst the neighbouring fold exhibits the reverse condition, as may be seen on the map (Fig. 47). The marked folds of Stangenes—Vagge and of Tananes (at Gavesluft there occurs an overthrust-fold) are dying out SW of the Tana Mountain: farther towards SW marked folds again occur, laterally displaced in relation to the former.

As to the tectonical conditions east of the Tana River, see p. 93.

West of the head of the Tarmfjord the lower tillite is located at a level of at least 100 m above the sea, and dips towards WNW, whilst east of the fjord it occurs along the shore; farther east, at Çokkales, portions of the older series lie over the tillite. An inclined anticline has evidently passed onto a thrust fault. Also a part of the tillite at Çokkales seems to belong to the overthrust, perhaps inverted, mass. This Tarmfjord anticline is, however, dying out towards the south; whilst the ordinary, though inclined anticline, which forms the ridge between the Tarmfjord and the Smalfjord, grows more acute and overturned towards the south.

A result of the rotational stress is an undulation of the folding axes which causes doming of the anticlines; the Njukēagaissa mountain presents a prominent example of such a dome.

We find the most distinct signs of the presence of a rotational stress in the Čikkojok district, viz., the marked eastern strike of the folding axes near the sediment border. Holtedahl deals with this fact (1931, p. 276):

"In the greater part of the area west of the Tana river the strike is N or NNE, turning, however, rather markedly into a NE direction at the upper end of the fjord, —

— In sharp contrast to the northern or north-north-eastern direction mentioned above stand the ENE and E strike of the sedimentary beds near the area of crystalline rocks to the south. This eastern strike is, as emphasized in my paper of 1918, naturally explained through the existence of the solid Archean block, towards which the folds have been pressed, like waves against a shore. This feature seems to be a further proof of the correctness of the assumption at which I arrived through studies of the stratigraphy, that there must have existed a Varangerfjord dislocation at a very remote time, previous to the Caledonian deformation."

To this, I may add that in the Antebaktoaivve district, where the throw of the fault seems to have vanished, the strike of the folds is N 15—20 E.

A force, which meets a plane at an oblique angle, exerts a pressure perpendicularly to the plane, and also produces a rotational stress. The folds are developed not perpendicularly to the original force, but in a direction so that the angle to the plane is lower. Under continuous influence the angle will grow still lower on account of the rotational stress. In a medium which offers a perfect resistance, the effect would be the same at any distance from the plane; but in our case the medium (the rocks) will give way by deformations, the effect being especially distinct near the border but decreasing northwards, although also there we must take the rotational stress into account. As the folding by rotational stress takes place at the same time all over the area, while by direct compression the folding proceeds successively, I think it probable that the rotational has been the dominant factor in the foundation of the folds (their distribution) whilst the compressive stress has otherwise been the cause of their character (the incline, the overturning).

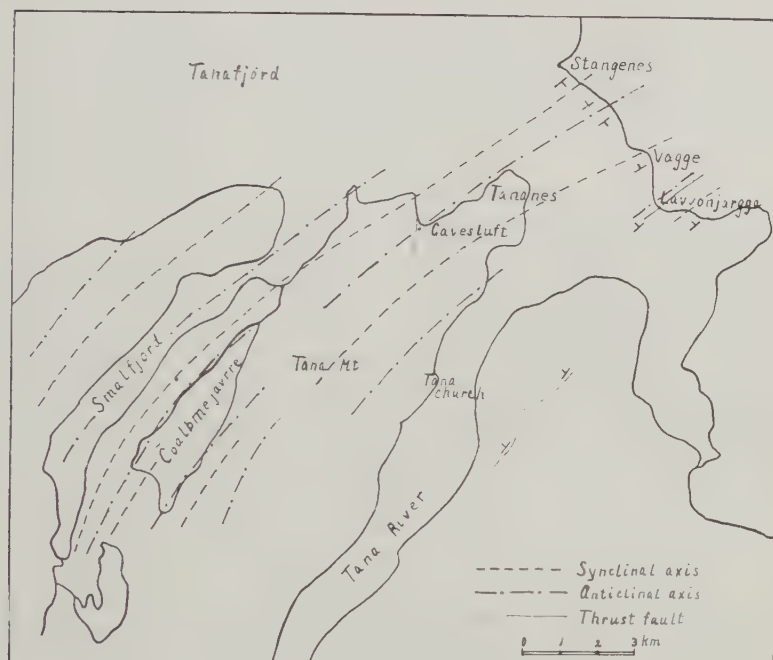


Fig. 47.

The turning towards NE of the folds near the head of the Tanafjord, is a feature on a larger scale than the phenomena just mentioned, but probably also this fact has connection with the border of the Pre-Cambrian crystalline block. The main direction of the Caledonian mountain range is from Finnmark northwards to Spitzbergen, thus the Varanger Peninsula must be regarded as an excrescence of the main range. The presence of the older tectonic line may perhaps be the cause for such an outgrowth towards east.

Whatever the outermost reason may be, there is a causality between the change in the trend of the folding axes and rotational stress. The local effects of this stress are greater where the change is greatest, and the marked doming of the folds at the uppermost end of the Tanafjord must be closely connected with the turning of the axes.

That the purely compressive stress has been active after the foundation of the direction of the folds seems also to emerge from the fact that the schistosity of the tillite on the outer part of the peninsulas between the Smalfjord and Vestertana has a more northern

strike than that of the folding axes. The schistosity cannot be first formed, as it has connection with overturning of the anticlines and thrust faults, things which must belong to the later stage of the developments of the folds.

3. *Vertical Planes of Dislocation.*

East of the middle part of the Tanafjord the trend of the zones is, taken as a whole, nearly towards the east, despite the fact that at detailed observations the strike is found to be about N 45° E. This W—E main direction appears from Lille Molvik and northwards, it being very conspicuous in the Trollfjord district. Tectonical disturbances are also more frequent as we go northwards. The cause seems to be the existence of W—E shear planes and block-dislocations along these, successively towards the east as we go northwards.

Such planes of dislocation also occur west of the fjord; in the Stappogiedde district they appear on the map as a series of short rivers, running towards the east. On some of these I have demonstrated dislocations; to me, the movements seem to have been chiefly horizontal, along nearly vertical planes.

Near Arasuolo, the northern block seems to have moved towards the east proportionate to the southern; whilst just north of Stappogiedde the relative movement of the northern block is towards the west. The degree of size of the movement is 10 m.

The same sort of W—E lines is also observed in the district west of the head of Vestertana. On the map it may be seen that the rivers either run along the strike of the rocks, or fairly directly towards the east. Thus, Hareelven runs along a dislocation line, the northern block having moved towards the east, also at the deep river-cut at "420" (9 km north of Njukëagaissa). In these cases the degree of size seems to be 100 m.

A distinct line of tectonic origin is seen across the ridge between Vestertana and the head of the Tarmfjord.

Also in other parts of the Tana district very marked lines, running W—E, are now and then seen, especially where the red and brown sandstone and shale make up the rock. They may be seen as precipitous stages, the surface being on one side a few metres higher than on the other, or they may appear as fissures, some few meters deep and broad. The outlet of the lake Snullejavrre

(3 km SSE of the head of Vestertanafjord) has formerly been at the northern end, along a canyon directly towards the west, but now the drain takes place to SSW along the strike. In the district around the head of the Smalfjord, lines of the types are often observed.

The W—E lines, which in some cases no doubt are due to planes of dislocation, might, perhaps, be explained as shear planes, which have come into existence by indirect folding. However, I think it is more possible that these lines, which are often visible several kilometres in length, and which cut both strong and weak zones of the strata, have been formed at a later time, as I suppose that they have connection with the thrust of the metamorphic rocks. These thrust movements seem to have taken place at a later stage in the orogenesis, after the actual folding. This will be more closely dealt with in the following chapter.

4. *The Metamorphic Rocks.*

These rocks are separated from the unaltered strata by a thrust plane, which is usually very distinctly seen as a line on the mountain sides (Pl. I, Fig. 2). The front of the metamorphic rocks is rather conspicuous; it forms a steep, the height of which may vary from a few metres to real mountain sides. On account of their metamorphic character, the rocks are easily distinguished from the unaltered. The rocks are mostly dark grey or greyish green mica schists and felspar-bearing sandstones, looking in a number of cases rather gneissose. Broadly speaking, they seem to be originally of about the same types as those in the unaltered strata, though they seem to be of coarser grain and richer in felspar than the latter. Now and then layers are seen which contain felspar and quartz, of size like peas. Real conglomerates also occur; in the district NE of Vaddasbakte, all the rock consists of a dark, pressed conglomerate, with the rock fragments lenticularly rolled out. The fragments are of different kinds: green fine-grained rock, granite, gneiss, quartzitic sandstone. The matrix is dark greenish, the minerals are somewhat crushed.

Conglomerate of the same kind, though the matrix is there not so crushed, occurs south of the head of the Ifjord. The smallest diameter of the stones is on an average a third of the largest one, which is up to 20 cm. At the head of the Ifjord, I also observed



Fig. 48. Pressed conglomerate, NE of Vaddasbakke.

a light-coloured conglomerate, the pebbles of which were very strongly flattened.

Reusch (1923) mentions from the Landersfjord a dark and a light conglomerate in connection with Pre-Cambrian granite; Th. Vogt (1919) mentions dark and light conglomerate from the Laksefjord without localizing it more exactly; he considers the conglomerate to be the basal beds of the sedimentary rocks in that area.

Pl. I, Fig. 1 shows the top of Vaddasbakke from east.

The rocks are greyish-green, gneissy, and cataclastic; in thin section, we observe crushed fragments of quartz, plagioclase and epidote. A specimen of a somewhat less cataclastic rock seems to be an original plutonic rock, it consists of quartz, plagioclase (polygonally bordered), yellowish-green amphibole, epidote; a little zirkon, and in fissures also carbonate and chlorite. Before the very front there also occur portions of a black rock, which consists of fibrous serpentine with some epidote and iron-ore (probably ilmenite). The same sort of rock also occurs one place nearer to the Ifjord valley, viz. NE of Gozavarre, at the base of the metamorphic rocks.

The dip of the thrust plane varies; in the environment of the Ifjord valley, the dip is about 10° , at the place where the border crosses the Langfjord valley it is about 15° , and, south of the Lang-

fjord, about 30° . Near the border the metamorphic rocks are not folded, the stratification (where such may be seen, e. g. in the Ifjord valley) is parallel to the schistosity, or forms a very acute angle to it.

A distinct striation on the planes of schistosity shows the direction of the movement of the metamorphic rocks. Between Vaddasbakke and a place about 10 km WSW of the head of the Langfjord, the thrust has proceeded towards $S\ 45^\circ - 50^\circ\ E$, but farther along the Langfjord the direction is $S\ 30^\circ - 40^\circ\ E$. Consequently, the corner of the border, WSW of the head of the Langfjord, is not an occasional result of erosion.

A problem presents itself: are the thrusting of the metamorphic and the folding of the unaltered rocks contemporaneous? In my opinion they are not; the folding seems to be prior to the thrusting.

Firstly, the thrusting has not affected the underlying rocks very much. Certainly, close to the thrust plane the strata are strongly disturbed and the rocks are crushed, but only a few metres off no effect is seen.

Secondly, the trend of the folding axes in the district between Vaddasbakke and the Langfjord is N, in part, a few degrees west of north; the folding cannot be due to a force, the direction of which was $S\ 45^\circ - 50^\circ\ E$, this would cause a trend more or less W—E. From Porsanger, Holtedahl (1918, p. 281) has observed the same case.

Along the Langfjord the trend of the folds is parallel to the border of the metamorphic rocks, about $N\ 40^\circ - 45^\circ\ E$, and per-



Fig. 49. Pressed conglomerate at the head of the Ifjord.

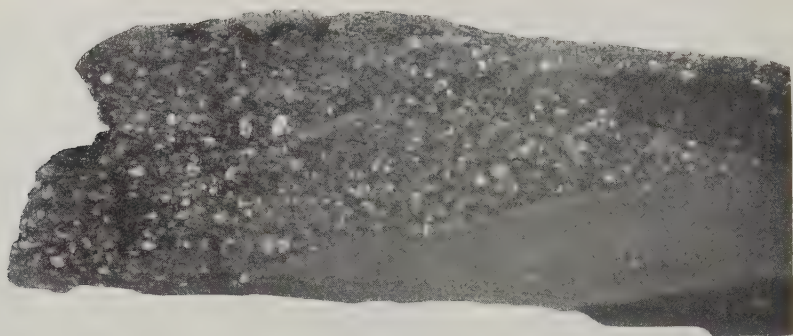


Fig. 50. Metamorphosed arkose, head of the Langfjord.
The section has been cut at right angles to the greatest strain axis.
Grains of quartz and felspar are seen. $1/2 \times$.
L. Monsen phot.

pendicular to the direction of the thrust. The folds might in this case perhaps be due to the movement, but more probably the agreement is in a degree occasional; in both cases, a turning of the trend has taken place, which must be due to greater features of the Caledonian mountain range.

It is, however, probable that the pressure which caused the overthrust has left certain traces also in the area of the unaltered rocks. Thus, I think the west-east dislocation lines may have connection with it. A force from NW will try to develop two sets of shear planes, one set with the direction N—S, and one W—E; but assuming a solid block to the south, only the W—E lines will develop, as dislocations in the direction N—S cannot take place. On account of this block also a rotational stress will come into existence, also by this stress the W—E shear planes will develop more strongly than the N—S planes, as the last-named are rotated out of the plane of maximum shear. (Willis, B. and Willis, R., 1934, p. 133.)

Holtedahl has informed me that north of the Langfjord, in the metamorphic complex, he observed tectonic lines running W—E. The thrusting force will affect the thrust masses as well as the rocks in front of them, thus these lines may very well belong to the same system as that just described. The presence of such lines both in the metamorphic and in the unaltered rocks is rather an indication that those in the unaltered rocks are not formed by the folding.

What I have now put forward, must be regarded as reasons in support of the view that the W—E running lines may have been developed in connection with the thrusting of the metamorphic masses. No proof that they are not younger is, however, at hand.

5. *The Main Thrust Plane, and the Origin of the Metamorphic Rocks.*

It is worth noting, that the metamorphic rocks are not folded near the thrust plane, but further off they are folded. On the north side of the Langfjord, they lie in gentle undulations, farther north, the intensity of the folding increases, and on the Nordkyn Peninsula, the strata are strongly folded. According to Høltedahl (1918, p. 281, and 1931, p. 276), the trend of the folding axes is N about 30° E.

We thus have the following phenomenon: The unaltered strata below the thrust plane are folded with the trend of the axes NNE or NE, likewise, the metamorphic rocks some distance north of the border, but not near the thrust plane. The conditions are explained by assuming that the intensity of the folding has decreased towards the depth, and that the main thrust plane has been formed below the folded part of the strata — quite naturally, as the solidity of a series of strata is increased by the folding.

Several factors suggest that when going towards east between Vaddasbakte—Berlevåg, we meet even younger beds. The degree of metamorphism seems to decrease in this direction, as far as I can judge it in the field, but this, however, is no good foundation for interpretation owing to different susceptibility of rocks to metamorphism. More important is the fact that the rocks NE of Vaddasbakte seem to originate from the basal part of the sedimentary formation, and that the top of Vaddasbakte seems to be a thrust mass of Pre-Cambrian rock. In my opinion, there can be only little doubt that the dark-coloured, pressed conglomerate is the same as that observed by H. Reusch and Th. Vogt in connection with Pre-

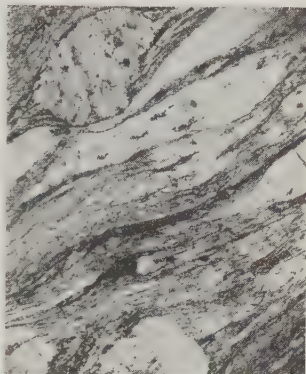


Fig. 51. Thin section from the specimen Fig. 50, cut parallel to the greatest strain axis. Nic. $\pm$. $9\times$. J. F. Stadheim phot.

Cambrian granite, and which was considered to be the basal conglomerate of the sedimentary rocks in the Laksefjord district.

I have previously mentioned that the dip of the thrust plane increases from the Ifjord valley towards NE. (Most southerly, on the Vaddasbakte mountain, however, it seems to be comparatively steep, 20° à 30° . I have made no exact measurement there.)

Holtedahl (1918, p. 279) calls attention to the fact that in the Berlevåg district no distinct border between the unmetamorphic and the metamorphic rocks can be seen, but only a zone of transition; moreover, the dip of the phyllite-quartzite strata is steep, whilst in the other border-districts the metamorphic rocks have small angles of dip. The metamorphic rocks in the Berlevåg district are apparently coherent with the unmetamorphic. Probably, no considerable thrust has taken place there, but mainly a crowding. Such a compression, perhaps, causes greater disturbances in the neighbouring unmetamorphic rocks than a thrust along a nearly horizontal plane would have done; at all events, the tectonic disturbances in the district Trollfjord—Store Molvik are far greater than those seen at the border farther towards SW.

It is, however, rather natural that the dip of the thrust plane is steeper at the higher levels of a formation, as a horizontal thrust plane will usually cut upwards because the least resistance is made from above. Theoretically the angle between the thrust plane and the horizontal plane will be 45° .

Th. Vogt (1929) has given a very brief account of his investigations in the Laksefjord district. According to him, the tectonical conditions at the Pre-Cambrian window at the upper part of the fjord are very interesting. The granite is divided into five various masses at least, thrust one over the other, and separated by younger sediments.

It may be questionable whether in this area Pre-Cambrian rocks can be found, which have not moved at all but, probably, most of them have not been displaced any long distance. According to Reusch and Vogt, the sedimentary rocks are nearly unaltered, though tectonical disturbances are abundant. Vogt uses the term Porsanger sandstone, and he says, without specifying the localities, that the metamorphic series lies discordantly on folded Porsanger sandstone,

separated from this by a thrust plane. The degree of metamorphism can be traced through the chlorite-stage and the garnet-stage, to facies containing garnet and amphibole, the least metamorphic rocks near the upper end of the fjord. I suppose that these observations have been made on the west side of the fjord. It would be interesting to know at which locality the border of metamorphic rocks reaches the fjord, in view of the correspondence to the border east of the fjord. As the direction of the border SE of the fjord is towards SW, there is in the Laksefjord district evidently a break, or, at any rate, a marked turning of the trend of this border. The thrust plane west of the fjord is most probably different from that east of the fjord, and the rocks above them belong to different sheets. If it is correct that the rocks at Vaddasbakke are Pre-Cambrian crystalline or at any rate that the conglomerate NE of Vaddasbakke corresponds to that from Landersfjord, then we may approximately state the maximum of the thrust of the Vaddasbakke sheet, the distance between Landersfjord and Vaddasbakke being about 15 km.

As to the age problem of the metamorphic rocks of Finnmark, Holtedahl's find in 1933 of tillite at the Kamøyfjord near North Cape is very important. The rock is somewhat metamorphic, but the tillite character is beyond doubt. It lies in a complex of metamorphic sediments with intrusions of granite.

Broadly speaking, we can say that the metamorphic sediments of Finnmark belong to the Eo-Cambrian series. Regarding the rocks of the Nordkyn Peninsula, we find rocks about similar to those in the Tana district, viz., quartzites, and dark, now phyllitic, arenaceous shales.

As regards the age of the deepest strata at the upper end of the Laksefjord, I would not omit to point out the similarity between the dark conglomerate and conglomerates in the Raipas series, which I have had an opportunity of seeing in the Repparfjord, near Hammerfest. However, the similarity between two conglomerates does not state very much, beyond saying that the material has derived from similar rock types, and that the geologic conditions were similar. The matrix of the Ifjord conglomerate is dark, zoisite-epidote and chlorite is abundant, the material having apparently derived from basic rocks.

VI. Autochthonic Eruptives.

One occurrence of an autochthonic eruptive rocks has been found in the area investigated by me. About 2 km NE of the outlet of the Kistedal river, on the shore line, I found outcrops of a fine-grained, dark, gabbro. The minerals are: plagioclase, pyroxene, and iron-ore, further, apatite, a little quartz, and secondary hornblende. Plagioclase is zoned, core about 65 An, rim 40 An and less.

The crags were surrounded by gravel or water, I did not see the rock cut the sedimentary rocks (the fossiliferous stage).

O. Holtedahl has told me that in the metamorphic area north of the Langfjord he found in 1933 a dyke of a diabase or gabbroid rock.

According to Holtedahl (1918) dykes of diabases are common on the north side of the Varanger Peninsula.

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Plate 1.

- Fig. 1. The front of the metamorphosed rocks. The Vaddasbakke mountain, seen from the east.
- » 2. The thrust plane, with north-western dip, is seen in the mountain side. Between Vaddasbakke and Gozavarre.
 - » 3. To the left the point of the Digermul Peninsula and the Digermuldal valley, seen from the Langfjord. Phot. O. Holtedahl.



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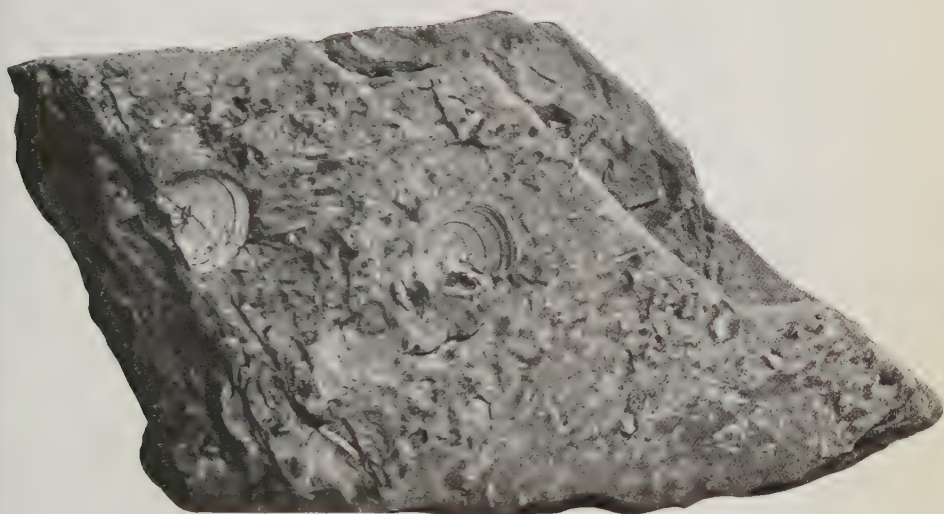


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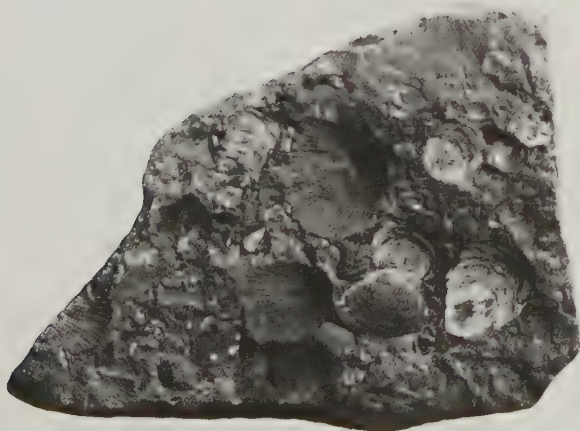
Plate 2.

Fig. 1. Thin-bedded sandstone with *Lingulella*. Boksjokka. (Text, p. 108.) Nat. size. Phot. L. Monsen.

- » 2. Thin-bedded sandstone with *Lingulella* and *Billingsella*. Boksjokka. (Text, p. 108.) Nat. size. Phot. L. Monsen.



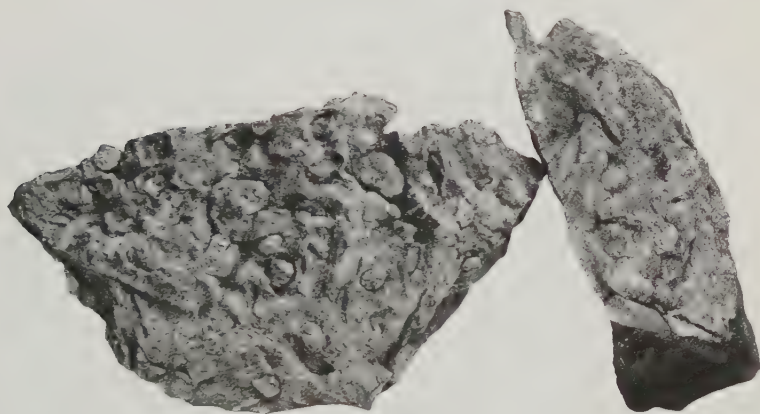
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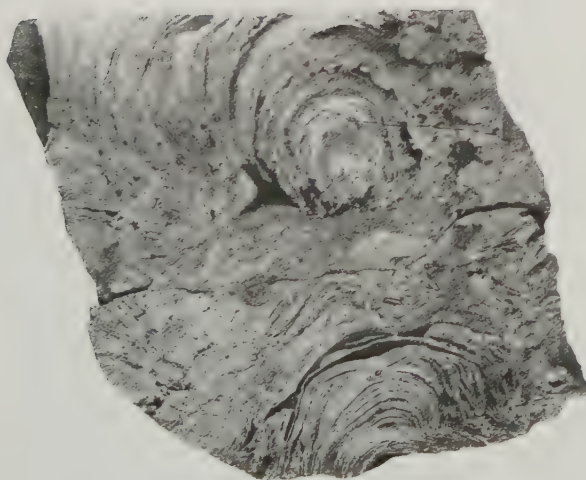
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Plate 3.

- Fig. 1. Sandstone with "problematic trails". Duolbasgaissa. (Text, p. 106.) $\frac{1}{2} \times$. Phot. L. Monsen.
- » 2. Boulder from the lower tillite. Dolomite with stromatolites. Gapperas. $\frac{1}{2} \times$. Phot. L. Monsen.



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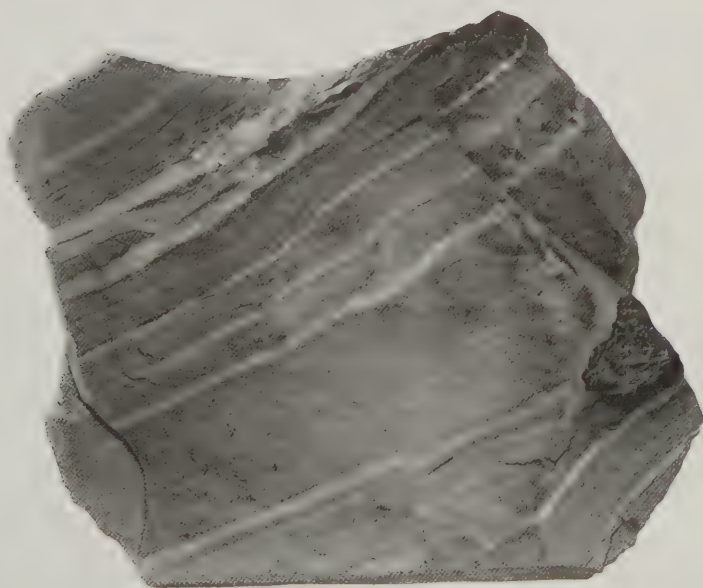
Plate 4.

Fig. 1. This banded, red-violet and yellowish, mudstone occurs in the lower tillite west of the Tarmfjord. (Loc. No. 9, text p. 97.) $\frac{1}{2} \times$. Phot. L. Monsen.

- » 2. Red-coloured, banded shale, with a gneiss pebble in the lower, right, corner. From the lower part of the lower tillite, west of the Tarmfjord. $\frac{1}{2} \times$. Phot. L. Monsen.



1



2

MOLYBDÉNGLANSFOREKOMSTENE I KNABEHEIA (FJOTLAND)

EN MALMGEOLOGISK STUDIE

AV

† JAKOB SCHETELIG

På møtet i Norsk geologisk forening 12. mars 1925 holdt professor Jakob Schetelig et foredrag: Om de geologiske forhold i Knabeheia. I referatet fra møtet, Norsk geol. tidsskr. 8, 1925, p. 226, står det, at foredraget vil bli trykt i tidsskriftet. Det har også hele tiden været hans mening å publisere dette foredrag, som vakte så stor interesse da det blev holdt. Fra interesserte er det ofte kommet spørsmål efter det.

Efter hans død 17. oktober 1935 blev det ikke funnet noget manuskript til foredraget. Det har sannsynligvis aldri været skriftlig utarbeidet i sin helhet.

Imidlertid har fru Borghild Schetelig skaffet red. manuskriptet til nedenstående malmgeologiske studie. Den er utarbeidet efter at foredraget var holdt og refererer hovedtrekkene av deler av foredraget.

Innledning.

De norske forekomster av molybdénglans er genetisk knyttet til sure eruptivbergarter, fortrinsvis granitter, og tilhører som regel granitterupsjonenes pneumatolytiske og hydrotermale fase. For en enkelt forekomst, Vatterfjord i Nordland, er påvist den genetiske sammenheng med en intermediær eruptiv, en syenitt (Th. Vogt). De fleste og viktigste forekomster er av prekambrisk alder, fortrinsvis knyttet til de senarkeiske granitter, men forekomster av molybdénglans er også påvist samhørende med granitter av kaledonisk alder. (Skjoldevik ved Haugesund, Laksådalen i Salten) og av devonisk¹ alder (Oslofeltet, hovedsakelig forekomster samhørende med den yngste granitt, Drammensgranitten). Analogien mellom dannelsen av tinnstensforekomster og forekomster av molybdénglans er forlengst

¹ Dette er skrevet før opdagelsen av permformasjonen i Oslofeltet. (Red. anm.).

påvist, for de norske forekomsters vedkommende først fremholdt av J. H. L. Vogt. I det hele kan man vel si at de norske molybdénglansforekomsters genesis generelt sett er nogenlunde klar. Men angående enkelte forekomsters geologi foreligger det ikke stort. Otto Falkenberg har gitt kortfattede summariske oversikter over en del av disse forekomsters geologi, og har særlig gjort opmerksom på den i teknisk henseende viktige forskjell mellem de sørlandske — særlig Knabeheias — impregnasjonsmalmer og de malmførende kvarts- og pegmatittganger som er representert i Telemarken, f. eks. ved Dalen og Haugholmen (ved Bandakslø). Sv. Blekum har fortjenesten av å ha påvist, at den malmførende bergart i Knabeheia er en egen bestemt granitttype, som uten vanskelighet makroskopisk lar sig holde ute fra andre granitttyper som forekommer i malmfeltet. Det er den typiske impregnasjonsmalm man har ved grubene „Knaben 2“ og „Benkehei“.

Knabeheias geologi.

Knabeheia er betegnelsen for Knaben gårds felles utmark og omfatter en strekning på ca. 5 kvadratmil fjellhei. Knaben gård ligger i Fjotland i Kvinas dal 65 km fra Fedefjorden. Kvinas dal går N—S, ved Risnes faller Knabeelva i Kvina, den renner gjennom den Ø—V gående Knabedal, et dalføre som fortsetter rettlinjet østover like til Åseral. I skaret på vannskillet ligger Knaberøisen, som er bygget op hvor Åseral, Eiken og Fjotland støter sammen. I Knabedalen, 5 km øst for Knaben gård ligger store Knabetjønn, omkring dette grupperer malmfeltet sig med en bredde Ø—V av ca. 1 km, og en lengde av henimot 10 km.

Den geologiske bygning av Knabeheia er enkel og de optredende bergarter få. I en summarisk oversikt over Knabeheias geologi, som jeg meddelte i en gruberapport for vel 10 år siden, skilte jeg mellem eldre „gneis og gneisgranitt“ på den ene side og yngre „porfyrgrenitt“ på den annen side, dette er hovedbergartene i det egentlige malmfelt. Amfibolitt og andre hornblendebergarten nevntes som helt underordnede, kun optredende i smale bånd og linser der hurtig kiler ut såvel efter strøk som fall. Ved siden av disse bergarter har bergingeniør Sv. Blekum på grunnlag av erfaring fra grubedriften i Knaben gruber 1 og 2 og Ørnehommen gruber samt ut fra sitt kjennskap til det hele malmfelt kunnet utskille en

egen *malmførende granitttype*, hvis mest karakteristiske egenskaper er følgende:

1. bergarten er tydelig stripet med utpreget stresstekstur,
2. fattig på mørke mineraler,
3. rik på kvarts (både primær og sekundær),
4. fører konstant impregnasjon av sulfider, molybdénglans, kobberkis, magnetkis og svovlkis.

Bergartene i Knabeheia viser uten undtak en mer eller mindre utpreget paralleltekstur. Mest fremtredende kommer dette tilsyne i det eldre kompleks av gneisser, øiegneiser og amfibolitter, minst hos den yngre lyserøde eller grå porfyrgranitt. Strøket er konstant SSV—NNØ og fallet monoklinalt ØSØ, gjennomsnittlig 20—30°. Lokalt kan hellingsvinkelen veksle endel, mine målinger viser således at fallet kan gå ned til 15—20° og op til 40—45°. Disse vekslinger synes å skyldes små fleksurer.¹ Innen Knabeheias molybdénglansførende malmfelt som strekker sig fra Kvina grube nordenfor Smalevatn i nord og til Bragold og Hommen gruber på overgangen til Litleådalen i syd, er strøk og fall ganske merkelig konstante.

I Knabedalen, østover langs veien til grubene fra Risnes forbi Knaben gård (ca. 400 m o. h.) og frem til Knabetjønn (ca. 600 m o. h.) med omgivelser er iaktatt linseformede og båndformede mindre partier av eldre gneis og amfibolitt. Øst for Knabetjønn møter man andre forhold. Jeg har gått op en rekke parallelprofiler her, og det viser sig overalt, at det opover skråningen stadig optrer flere bånd og linser av de eldre bergarter (gneis og amfibolitt) i granitten. De er innleiret konformt med granittens paralleltekstur, med lengderetning og skifrig-het parallel strøket. Mektigheten varierer fra en dm og op til mange m. Mengden av innleiringer av eldre bergarter tiltar efter hvert, og når man kommer på platået i ca. 800 m's høide er det eldre gneiss-kompleks helt dominerende, men viser her konstant tallrike injeksjoner av den yngre granitt. Disse granittiske lagerganger i det eldre gneiss-kompleks er ofte utpreget porfyriske, men ikke sjelden finkornet

¹ Det ensartede strøk av parallelteksturen og det monoklinale fall som jeg har iaktatt i Knabeheia kan følges over meget store strekninger på denne kant av landet. Jeg har iaktatt det langs hele Sirdalsvatnet og dets omgivelser. Videre opover vestre og østre Kvinesdal, fremdeles på heiovergangen mellem Tonstad i Sirdalen og Risnes i Kvinesdal, herfra videre østover Knabedalen til Knabetjønn og frem til Knaberøisen på overgangen til Åseral.

aplittiske. Det eldre gneiskompleks med granittiske lagerganger viser samme strøk og fall som parallelteksturen i den yngre granitt. Oppe på det nevnte platå ligger flere av de større molybdéngrubber i Knabeheia: Kvina grube, Knaben 1 (Storgruben), Lille Knaben, Roma, Sandtjønn-skjerpene o. fl. Alle disse forekomster finner man i det eldre gneis-amfibolittkompleks med lagerganger av den yngre granitt. Det danner en vel begrenset, karakteristisk sone etter strøket med typisk båndstruktur, eller platearkitektur med strøk og fall konstant. Man kunde også utrykke det så, at denne sone danner en del av taket over en mektig under stress injisert granittmasse med primær paralleltekstur. Nu viser det sig imidlertid, at den granittinjiserte gneissone mot øst overleires av samme granitt, som ligger under nede ved Knabetjønn. Gneissonen blir derfor å opfatte som en stripe, eldre fjell innkilet i granitten.

Det er av betydning for den foreliggende oppgave, at den felt-geologiske undersøkelse har vist, at det molybdénglansførende strøk i Knabeheia, som er av nogen betydning, er begrenset til den granittinjiserte gneissone og den nærmest underliggende granitt.¹

Genetisk samhørende med den yngre røde „porfyrgranitt“ optrer en hel del ganger av forskjellig slags. Porfyriske og aplittiske granittganger i det eldre gneiskompleks er allerede nevnt, de optrer uten undtak som lagerganger.

I granitten selv er også aplittiske lagerganger almindelige. Som regel er de injisert konformt med granittens paralleltekstur, men jeg har også iaktatt at de lokalt skjærer skrått over granittens skiffrighet under en liten vinkel. Tykkelsen varierer fra tynne årer på et par cm og op til flere meter mektige ganger. Jeg vil allerede her fremheve som et viktig trekk, at årer og ganger av aplitt også optrer inne i og ved grensen av den molybdénglansførende granitt („malmgranitten“), innen malmsonen ved Knaben 2 grube har jeg funnet aplittganger såvel i gruben som i dagbruddet malmførende, oftest spredt impregnasjon av MoS_2 , men også storbladet molybdénglans. Jeg kommer til dette under den nærmere omtale av malmgranitten.

¹ Adskillige molybdénglansanvisninger i Kvinesdal og i Sirdalen viser en helt analog forekomstmåte, således Lindefjellsskjerpene i Fjotland og forekomstene ved Sandsmark og Åvedal ved Sirdalsvatnet. Her optrer molybdénglansen i eller ved partier av eldre gneis-amfibolittbergarter innleiret i granitt.

Sammen med aplittgangene og helt analog disse optrer også granittpegmatitt, som regel i tynne årer fra ca. 5 cm og op til 25—30 cm tykke. Det er endogene pegmatittganger injisert parallel granittens skifriighet (paralleltekstur). De er i det store og hele sjeldnere enn aplittgangene.

I det eldre gneiskompleks optrer enkelte større pegmatittiske lagerganger. Den betydeligste og viktigste er den store, rikt malmførende pegmatittgang ved Kvina grube ved nordenden av Smalevatn. Sammen med denne pegmatittgang optrer et mektig leie av mørk røkkvarts, som eiendommelig nok i stor utstrekning viste sig spekket med krystaller av augitt og hornblende (visstnok vesentlig uralittisert augitt). Særlig rik malmføring optrådte i og ved denne røkkvarts. — I motsetning hertil er de almindelig optredende, smale, hornblende-førende pegmatittårer ikke molybdénglansførende.

Den store pegmatittgang ved Kvina grube med de mektige masser av røkkvarts fører over i de rene kvartsganger, som hvad jeg senere skal søke å vise skal stå på overgangen mellem granittens pneumatolytiske og hydrotermale fase. Disse dannelser er først og fremst representert av langstrakte tynne linser, årer og ganger av kvarts med sulfider (fortrinsvis MoS_2 , men også kobberkis og svovlkis), injisert parallel skifriigheten i det eldre gneiskompleks og i granitten selv. — Store kvartsinjeksjoner med grovbladig molybdénglans i klumper er sjeldne. Mest fremtredende er de op til et par meter mektige, linseformige injeksjoner i gneis og amfibolitt ved Knaben 1 (Storgruben), hvor det blev påtruffet rene masser av molybdénglans av op til 5 tons vekt. Kvartslinsene ved Knaben 1 viser forholdsvis kort utholdenhet efter strøket, men er fulgt ved grubedriften ca. 30 m mot dypet med dragning i felt sydover. Tobiasskjerpene øst for St. Smalevatn viste sig ved forsøksdrift å være mindre kvartslinser, som raskt kilte ut mot dypet, men for øvrig helt analoge med kvartslinsene ved Knaben 1. — Forekomster av denne type synes utelukkende knyttet til det eldre gneiskompleks med lagerganger av porfyrisk og aplittisk granitt.

Innen hele malmsonen i Knabeheia finner man ganske generelt malmføringen i forbindelse med de tynne kvartsinjeksjoner parallel skifriigheten. Tykkelsen kan være fra noen få cm og op til et par dm, men dessuaktet er de som regel meget utholdende efter strøket og kan følges sammenhengende $\frac{1}{2}$ —1 km og mere. Istedenfor en sammenhengende gang finner man ofte et strøk av tynne langstrakte kvartslinser som kiler ut og avløser hverandre, ofte med litt sprang i nivået. Kvartsen

er ofte røkkvarts, sjelden ren hvit melkekvarts. På forvittringsflaten av det utgående ser man ofte fordypninger og huller efter mekanisk utvitret molybdénglans.

Kvartsinjeksjoner av denne art er iaktatt: 1) i eldre gneis og amfibolitt, 2) langs grenseflaten mellem disse og yngre granitt og 3) innen den yngre granitt selv, og også her alltid parallel skifriheten. Foruten kvarts og sulfider er flusspatt funnet en enkelt gang. Sulfidene — som nevnt i regelen overveiende MoS_2 — optrer i kvartsen selv, men også innblåst i sidestenen, i gneisen som små „patches“ fortrinsvis ophopet ved biotittrosene, i amfibolitt som jevnt fordelt impregnasjon i små skjell. Eksempler på det siste har man i Ljosdalsskjerpet og i heng av den store kvartslinse ved Knaben 1. Innen den yngre granitt kan disse strøkganger av kvarts med ganske liten mektighet følges over lange strekninger, og praktisk talt alltid ledsaget av malmføring, også her finner man molybdénglansen dels i kvartsen selv og dels innblåst i granitten noen få cm utover til begge sider av kvartsgangens grenser. Som eksempler kan nevnes Risnesskjerpene til vest for Knaben 2. Bragold grube og Hommen grube sydligst i malmfeltet på overgang til Litleådal.

Den malmførende granittypus („molybdéngranitten“) er alltid rik på kvartsinjeksjoner, dels som virkelige strøkganger med stor utholdenhet efter strøket, dels som tynne linseformede injeksjoner ledsaget av „patches“ av MoS_2 . Den malmførende granitt kan være helt spekket med slike linser, og malmkvaliteten synes å stå i direkte relasjon til mengden av kvartsinjeksjoner.

Yngre enn de her nevnte aplitt-, pegmatitt- og kvartsinjeksjoner efter strøket og parallelteksturen er smale årer og ganger av granitt-pegmatitt, som følger retningen av vertikale diaklaser tvers på strøket, altså med et Ø—V forløp (nøaktig ØSØ—VNV). Noen få av dem forløper også med retning NV—SØ eller NØ—SV efter mindre utpregede diaklaser, som danner ca. 45° vinkel med hoveddiaklasene. Ganger av denne type når sjelden over 20—30 cm's mektighet og de er relativt lite hyppige. Sammen med dem og med samme retning optrer også kvartsganger av hvit melkekvarts. De tverrgående pegmatitt- og kvartsganger er aldri malmførende, i ethvert fall er molybdénglans aldri funnet. Derimot har jeg i dagbruddet i Knaben 2 — altså innenfor malmsonen ved denne grube — iaktatt magnetkis og kobberkis i en slik tverrgående pegmatittåre, men ikke molybdénglans. Jeg kommer til dette senere.

De tverrgående pegmatitt- og kvartsganger er de yngste dannelser som tilhører Knabeheias yngre granitt.

Yngst er diabasgangene, som gjennomsetter det hele bergartkompleks med Ø—V forløp, idet de følger de ovennevnte vertikale hoveddiaklaser. Innen Knabeheias malm-distrikt er iaktatt en 3—4 stykker av disse ganger, hvorav den største i Ørnehomgjelå er ca. 10 m mektig. Disse diabasganger turde være å sammenstille med tilsvarende ganger i Ekersundsfeltet og kan i likhet med disse følges milevidt i sammenheng.¹ Av praktisk interesse er, at disse ganger overskjærer malmsonene, således overskjærer Gjelaången Ørnehommens, Lille Knabens og Spillebrokskjerpenes malmsoner. Diabasgangene er således distinkt yngre enn granittens pneumatolytisk-hydrotermale fase.

*

(Her følger et avsnitt om de opptredende bergarters petrografi, spesielt med hensyn på den røde „porfyrgranitt“ og den grå molybdénglansførende „malmgranitt“. Et resymé av resultatet er anført nedenfor).

Den MoS_2 -førende malmgranitt er efter de opptredende hovedmineraler en ordinær biotittgranitt, hvori under påvirkning av en hydrotermal pneumatolyse optrer en rekke omdannelser og nydannelser: Biotitt er i stor utstrekning klorittisert og viser innleiring av nydannede muskovittlameller, likesom også flusspat omtrent utelukkende optrer som nydannelser i bitte små korn inne i den omvandlede biotitt. — Plagioklasen er sonarbygget med kjerner av oligoklas og med randsoner av ren albitt. Kjernen viser sig sterkt angrepet med nydannelser av muskovittskjell, mens randsonen alltid er helt intakt. Myrmekittdannelser, som ikke er sjeldne, kan tilhøre nydannelsene under den pneumatolytisk-hydrotermale fase. — Et annet viktig trekk er det nesten absolutte fravær av oksydisk jernerts, magnetitt er kun iaktatt som rester. Det synes som om jernsulfider, magnetkis og svovlkis er dannet på magnetittens bekostning. Svovlkis optrer i regelen

¹ Den store gang i Ørneholm-gjelå kan således følges flere km østover til fjellryggen øst for Bergetjønn, og det er efter retningen utvilsomt samme gang man finner igjen vestover i Knabeelvas leie, hvor broen går over elven nedenfor Knaben gård. Efter sikt fortsetter samme gang vest for Kvina oppe i dalsiden overfor Risnes, hvor den tegner sig som en retlinjet, smal kløft i fjellsiden, rik på vegetasjon. Man kan så se kløften fortsette til synsranden i fjellene, hvor den tegner sig som et lite hakk.

som vel begrensede terninger, mens magnetkis og sammen med den kobberkis er å se i uregelmessig optrafsete korn, så begge disse mineraler gjør inntrykk av å være sekundært avsatt i en helt størknet bergart. — Molybdénglans finner man dels som tynne små skjell, i almindelighet fritt alene, sjelden sammenvokset med de øvrige sulfider, dels i krystalliske aggregater med subparallel sammenvoksing av flere krystallindivider. Karakteristisk er at kalkspatt alltid synes å ledsage de litt større aggregater av molybdénglans, dels omhyllende, dels innleiret mellom de enkelte krystalltavler. Også enkeltskjellene av molybdénglans er ofte ledsaget av kalkspatt. I kombinasjonen flusspat-kalkspat — sammen med rikelig sekundær kvartsavsetning — ser jeg beviset for at ertsimpregnasjonen i „malmgranitten“ er å opfatte som sekundært tilført under en pneumatolytisk-hydrotermal fase.

Den grå, molybdénglansførende malmgranitt er efter dette å opfatte som en begynnende greisendannelse av den røde granitt. Malmgranitten med sine aplittganger og finkornete, gneisliknende varieteter av samme alder som den røde granitt representerer soner parallel skifrigheten innenfor det store granitt-massiv, hvor den pneumatolytisk-hydrotermale virksomhet har hatt et maksimum.

Det ligger nær å søke en mekanisk forklaring på dette forhold deri, at de malmimpregnerte soner i granitten — altså de nuværende malmgranittsoner — har oprinnelig vært lettere gjennomtrengelige for gaser og oppløsninger, hvilket muligens skyldes en mere utpreget paralleltekstur grunnet sterkere stressvirkning nettop i disse soner.

TO THE PROBLEM OF BLACK GRAPTOLITE SHALES

TRACES OF GAS-BUBBLES PENETRATING
THE SURFACE-LAYERS OF THE BOTTOM

BY

LEIF STØRMER

WITH 1 FIGURE IN THE TEXT AND 1 PLATE

While examining and sorting Ordovician graptolites of the Palaeontological Museum in Oslo, I noticed a peculiar and characteristic preservation of certain species. In cases where the graptolites occur in great quantities on the surface of the black shale-slabs of the Ceratopyge Shale (3 a β) and the Lower Didymograptus Shale (3 b), the specimens are arranged in a peculiar way as described below. The position of the preserved graptolites suggests distinct conditions of the black mud in which the specimens were embedded.

Description.

Fig. 2 on the plate shows the surface of a piece of black shale from the Ceratopyge Shale (3 a β) of Stensberggaten in Oslo. The fauna of this shale which was described by Monsen (1925), contains species of *Bryograptus*, *Clonograptus*, *Triograptus*, and other genera. The figured slab shows a great number of fragmentary specimens of *Bryograptus ramosus* Brøgger (determined by Miss Astrid Monsen). The fragments do not quite cover the whole surface. With exception of the lower part, which expose a deeper and less fossiliferous layer of the shale, the shiny fossiliferous surface is interrupted by a number of more or less circular black spots which are barren of fragments. The diameter of the empty patches varies between 4—8 mm. Where a slightly deeper layer is exposed below the patches, it is possible to demonstrate that they do not continue as vertical canals, but rather occur as flat ellipsoids. The thick masses of graptolites surrounding the patches show a certain arrangement. Singular stipes are not projecting into the empty mud-discs, but on the contrary the stipes

are arranged somewhat parallel or rather tangent to the borders of the patches, which thus are framed by the graptolite masses.

Fig. 1 on the plate shows a more striking example of the same arrangement of graptolite fragments. The slab of black shale from the Lower Didymograptus Shale (3 b) of Galgeberg, Oslo, has numerous specimens of the very thin rhabdosomes of *Trichograptus bulmani* Monsen, recently described by Monsen (1937 p. 202). Also in this case the practically continuous cover of graptolite fragments is interrupted by circular empty patches with diameters from 2—3 mm up to 8—10 mm or even more when several spots are combined. As in the former case it is possible to show that the black spots form flat discs. By preparation a thickness of 0.5 mm of one of the discs is indicated. It appears very plainly in the photograph how the thin thread-like rhabdosomes of *Trichograptus* have a conform arrangement round the empty mud-discs. Within the packed clusters of graptolite fragments one notices how the single stems have a tangent position to the borders of the spots and form a perfect framework.

As it appears from the descriptions above, the characteristic structures found in two different stratigraphical horizons and in different genera of graptolites, are closely similar and must have been formed under the same conditions. It is obvious that the arrangement of the graptolite fragments is a primary one which took place on the surface of the bottom before the specimens were embedded in the black mud. If the empty mud-discs had been formed afterwards the rich fossil layer would have been penetrated without any disturbance of an original casual arrangement of the specimens.

Before we discuss the origin of the found structures, it is necessary to point out their difference from other mode of occurrences of graptolites. Graptolite rhabdosomes are often packed in fagots as may be seen in *Trichograptus* (Monsen 1937, pl. 17, fig. 7) and many other genera as the Silurian monograptids (Hundt 1936, fig. 5). Such structures have been referred to the action of currents or to a primary parallel arrangement in great-colonies.

The text-fig. shows a bunch of graptolite fragments, probably *Clonograptus* sp., from the basal Ordovician of Eiker. The ring-like arrangement evidently is due to current-action by which the bunch of intangled graptolite specimens obtained a rotating movement on the bottom. Although this may show a superficial resemblance to the

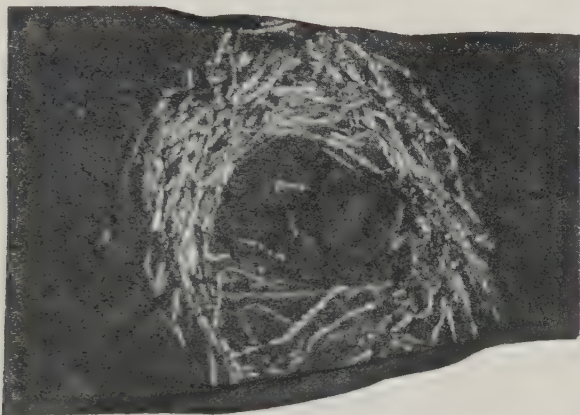


Fig. 1. *Clonograptus* (?) sp. 1. $\times$. From the basal Ordovician (2 e—3 a) of Lundebakken, Eiker. Old Collection. Nr. 208, Pal. Mus. Oslo.

The ring-like arrangement of the graptolite fragments is evidently due to current action.

structures shown on the plate, it is decidedly different. Besides the ring-formation the surface of the shale is barren of graptolites, while in the other cases a continuous cover of graptolites is interrupted by smaller "holes".

Interpretation of the structures.

The concentric arrangement of the graptolite specimens round the circular empty mud-discs shows clearly that the structure is a primary one formed before the graptolites were imbedded in the sediment. The "holes" were formed on the bottom while its surface was covered by numerous graptolite rhabdosomes. The origin of the empty spots can hardly be referred to burrowing organisms. In that case one would expect the broad openings to continue as canals through deeper layers of the shale. A burrowing form of that size would also have caused a greater disturbance among the light and delicate graptolite stems on the surface.

A more satisfactory explanation is obtained by assuming that the peculiar arrangement of the graptolites is due to gas-bubbles penetrating the graptolite-cover on the bottom. Gas-bubbles would be formed in the uppermost layers of the black mud and would be able to penetrate the surface layer by pushing aside the light graptolite stems. The graptolites would obtain a more or less concentric arrangement

with the branches as tangents to the border of the bubbles. The most typical arrangement is to be expected among the lightest and most thread-like forms. That explains why the structures are so distinct in the delicate *Trichograptus* (pl. fig. 1) and somewhat obliterated in the multibranched and more rigid *Bryograptus* (pl. fig. 2). Only favourable conditions: 1. a Rapid alternation between highly fossiliferous and more or less empty layers, 2. the presence of numerous small and light forms covering the bottom surface, would leave distinct traces of the bubbles.

The presence of gas-bubbles in the uppermost bottom-layers is typical of anaërobic conditions. Considerable quantities of methane (CH_4) may ascend as bubbles from the anaërobic bottoms.

The structures found may be explained as caused by gas-bubbles formed under anaërobic conditions and thus with further evidence support the current opinion that the black shales have been deposited on an unventilated bottom.

The black shales have by various authors been compared with the bottom deposits of the Black Sea. Recent studies by Strøm (1936) of landlocked Norwegian fjords have brought new material for comparison. Dr. K. M. Strøm has also pointed out to me that the structures here described resemble the arrangement, in the present-day lakes, of pine-needles on bottoms with ascending gas-bubbles. The view presented above is thus further supported. An alternation between black and light grey layers in our Lower Didymograptus Shale (3 b) indicates the changes from unventilated to ventilated bottom conditions (Størmer 1937 p. 276).

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PLATE

Plate.

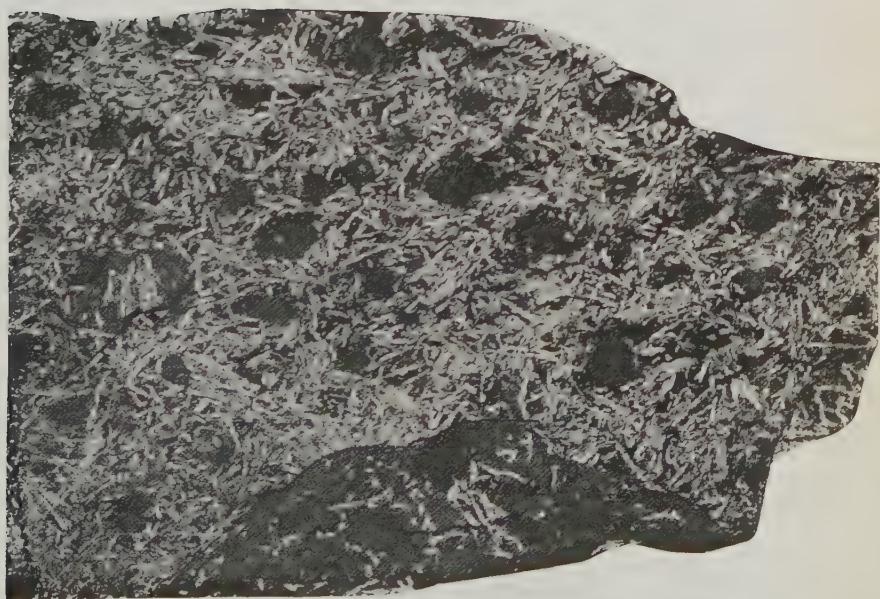
Fig. 1. *Trichograptus bulmani* Monsen. 1 $\times$. From the Lower Didymograptus Shale 3 b (probably upper part 3 b γ — 3 b δ) of Galgeberg, Oslo. A. Heintz, T. Strand, L. Størmer coll. 1936. Nr. 60044, Pal. Mus. Oslo.

» 2. *Bryograptus ramosus* Brøgger. 1 $\times$. From the Ceratopyge Shale 3 a β (155—180 cm below the Ceratopyge Limestone 3 a γ) of Stensberggaten, Oslo. J. Kiær coll. 1909. Nr. 59399, Pal. Mus. Oslo.

The photographs are not retouched.



1



2

FELDSPAR EQUILIBRIA AND THEIR IMPLICATION I

BY

TOM. F. W. BARTH

WITH 4 FIGURES IN THE TEXT

In the present paper synthetic melts and natural rocks have been compared in order to find the laws governing the interrelation between the individual feldspar phases met with in rocks. Some of the preliminary results have been published elsewhere more than three years ago (Naturen 1934, pp. 190—192) By comparing the results of recent synthetic studies with new data obtained from natural rocks through several years of gathering, some conclusions now seem so definite as to justify publication, although many questions still await their explanation.

For the present study I have received material from: The late Dr. H. S. Washington; rocks from Mte. Amiata, Italy.

Dr. W. F. Foshag, National Museum, Washington, D. C.; rocks from Siebengebirge, Germany and from Gunnison Co., Colo.

Dr. C. A. Anderson, University of California; rocks from the Clear Lake Area, California.

Dr. C. Bugge, Director, Norges Geologiske Undersøkelse, rocks from southern Norway collected by Olaf Andersen.

The present paper falls in three parts.

I. The Feldspar Minerals Arranged as Reaction Series.

II. The Mixed Crystals.

III. The Feldspar Geologic Thermometer.

The Feldspar Minerals Arranged as Reaction Series.

A. Feldspar in Artificial Melts.

The composition of the rock-making feldspars can be expressed in terms of the mineral molecules Or (KAlSi_3O_8), Ab ($\text{NaAlSi}_3\text{O}_8$), and An ($\text{CaAl}_2\text{Si}_2\text{O}_8$). But the physico-chemical system formed by these three components is not a true ternary system under ordinary pressure, but due to the incongruent melting of Or with separation of leucite it is actually quaternary.

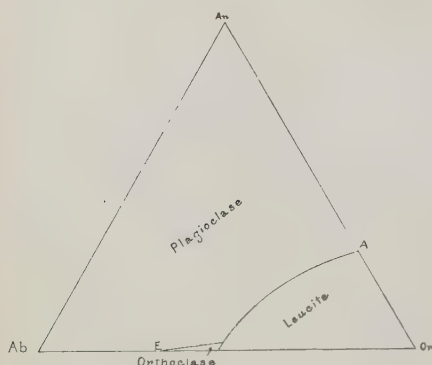


Fig. 1. Schematic equilibrium diagram of the system Orthoclase-Albite-Anorthite, being part of the quaternary system Silica-Leucite-Albite-Anorthite.

Although no quaternary silicate system has been completely studied in the laboratory the all-important equilibrium studies by Bowen and Schairer have now given so much information about the fusion relations of feldspar, that the application to igneous geology has become obvious.

In Fig. 1 a triangular diagram has been used to show the equilibrium relations in the quaternary system Or—Ab—An, the presentation is therefore by necessity inadequate, but nevertheless good enough for an approximate survey of the conditions. It has been constructed from various data published by Bowen and Schairer.¹

At the Or-corner leucite is the primary phase. The liquidus point is at about 1530° and the lowest temperature on the join Or—An is approximately 1375° (A in Fig. 1, but this is not a true eutectic, these parts of the diagram actually being governed by quaternary equilibria). Only in a very small field is orthoclase solid solution a primary phase. In the whole remaining area of the diagram plagioclase is the primary phase (including here soda-rich anorthoclase which physico-chemically represents the same phase). The lowest point on the fusion surface towards which all residual liquids will trend is at 33 Or, 67 Ab with a temperature of 1076° (E in Fig. 1).

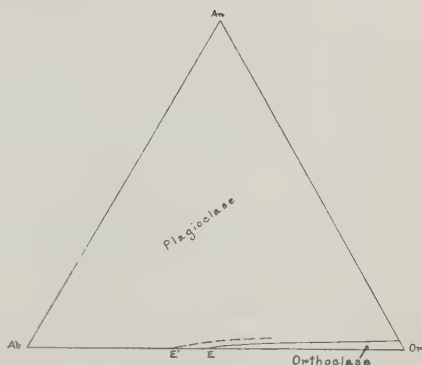
¹ N. L. Bowen, The Melting Phenomena of Plagioclases, *Am. Jour. Sci.* 33, 551, 1912.

J. F. Schairer and N. L. Bowen, Equilibrium Relations between Feldspatoids, Alkali Feldspars, and Silica, *Trans. Am. Geophys. Union* 16. Ann. Meeting 1935, p. 325.

N. L. Bowen, Recent High-Temperature Research on Silicates and Its Significance in Igneous Geology, *Am. Jour. Sci.* 33, 1, 1937.

Fig. 2. *Full line* illustrates schematically the equilibrium conditions on a section with 30 % silica in the system Silica-Orthoclase-Albite-Anorthite.

Stippled line refers to the equilibrium diagram of the truly ternary system Or-Ab-An under approximately 1000 Atmospheres.



In natural magma these relations will be somewhat modified, partly by presence of other substances, partly by heightened pressure. Substances of modifying influence are for instance water and other mineralizers. But at present it is hardly possible to say much about the character of their effect, no pertinent laboratory data being available. The effect of excess silica, however, has been shown by Bowen and Schairer to involve interesting consequences in igneous geology: Addition of silica causes the leucite field to shrink until it eventually disappears at about 30 % excess silica. The equilibrium conditions in a feldspar melt with 30 % excess silica are schematically and graphically shown in Fig. 2. Of course, this system is not ternary, and the triangle diagram of Fig. 2 cannot, therefore, give full information of the various equilibria. Schematically it shows, however, that no leucite field is present, and that the plagioclase field has encroached still further on the domain of Or-solid solutions, which now is restricted to a narrow zone in the lower right hand part of the diagram. The lowest point on the fusion surface is now at 48 Or, 52 Ab (+ 30 % excess SiO_2) where the temperature is around 1000° (E in Fig. 2).

The effect of pressure on feldspar melts is not known in detail, but can be estimated by applying the well-known thermodynamical equation of Clausius-Clapeyron giving the variation of the melting point, T , with pressure, P :

$$\frac{dT}{dP} = \frac{T \Delta v}{Q},$$

where Δv is the increase of volume attending the melting, and Q the heat absorbed.

The calculated rise of the melting point, $\Delta T/1000$ Atm., for Or, Ab, and An amounts to 10° , 25° , and 4° respectively.¹ But still another effect is produced by the pressure: it wipes out the leucite field. The mode of occurrence of leucite and its small density had long been taken as indicative of a reduced stability field at higher pressures, and recently Goranson² has succeeded in demonstrating experimentally, that under sufficient pressure orthoclase melts congruently. The consequence is that at such pressures the system Or—Ab—An becomes truly ternary. Just what the necessary pressure is, has not been stated, but this figure is of minor importance for the present discussion. Using the values given above for the increase of the melting points with pressure, and remembering Goranson's experimental finding, we now can form an opinion of the equilibrium conditions under a pressure of, say 1000 Atm. The field boundary between the plagioclases and the orthoclase solid solutions will be approximately as shown by the stippled line in Fig. 2.

In certain respects the equilibrium conditions are rather similar to those obtained under ordinary pressure with 30% excess silica. Again the lowest point on the fusion surface is on the Or—Ab join (at approximately 38 Or, 62 Ab and 1095° i. e. at E' in Fig. 2) and the field of the orthoclase solid solutions is reduced to a narrow strip in the lower right hand part of the diagram.

All information thus far obtained from experiments and from theoretical considerations serve to elucidate the crystallization process of rock magmas. Depending upon the chemical composition a magma may correspond to a point in the plagioclase field or in the orthoclase field of the present system.³ Accordingly either plagioclase or orthoclase will crystallize first, the composition of the residual liquid thereby in any case being pushed towards the boundary line. When

¹ For the values of the constants T , Δv , and Q , see R. Doggett Terzaghi, *Am. Jour. Sci.* 29, 1935 p. 374, where references to the original literature are given.

² R. W. Goranson, *Silicate-Water Systems*, *Trans. Am. Geophys. Union*, 17. Ann Meeting, 1936, p. 259.

³ If one recalculates the normative feldspar content of a rock to 100 per cent, $or' + ab' + an' = 100$, the composition of the normative feldspar can be plotted in Fig. 2, and thus its position in respect to the boundary curve shown. Since the curve is determined by two coordinates, for example ab' and an' , the equation of the boundary curve can be given as follows:

$$(an')^2 + 2ab' = 120 \text{ (approximately).}$$

the boundary line is reached a simultaneous crystallization of plagioclase and orthoclase solid solution begins, and thenceforth continues, until the lowest point on the fusion surface is reached. The position of this point is always on the Or—Ab join (no An present). Under surface conditions it corresponds to 33 Or, 67 Ab; but both increasing pressure and excess silica will tend to push it towards the Or-corner. Thus it would seem that all natural rest magmas should be enriched in an alkali feldspar containing about 40 % of the orthoclase molecule.

B. Feldspar from Igneous Rocks.

Now it remains to compare these results with observations on feldspars from igneous rocks. To this end rocks have been investigated containing as products of a simultaneous crystallization two feldspar phases; viz. plagioclase, and orthoclase solid solution. The feldspar phases were separated and analyzed individually. Thus the composition of the two phases which during the crystallization were in equilibrium with each other could be determined.

1) Feldspars from Mte. Amiata, Italy. These interesting rocks have been carefully described and analyzed by Williams.¹ For all details the reader is referred to his paper; suffice it here to state that the rocks consist of a more or less fine-grained ground-mass in which are distributed rather large phenocrysts of both plagioclase and sanidine. Several of the phenocrysts have been analyzed by Williams, but his analyses, which are now 50 years old, do not all come up to modern standards. Particularly doubtful are his alkali determinations which were made according to the old Berzelius method, which is inferior to the Smith method that is now universally

From this it follows that if the composition of the feldspars of a magma is such as to satisfy the equation, a simultaneous precipitation of plagioclase and orthoclase will take place in the magma. If the sum is larger than 120 the magma would precipitate only plagioclase. If less than 120 the magma would precipitate only orthoclase solid solutions; but this last condition, according to Ruth Doggett Terzaghi (op. cit.) does not obtain in primary magma. If therefore the composition of the feldspars of a rock meets the following condition:

$$(an')^2 + 2ab' < 120,$$

it would seem to indicate a replacement mode of origin of the rock.

¹ J. F. Williams, Monte Amiata und seine Gesteine, Neues Jahrb. Beil. Bd. 5, 1887—1888, p. 381.

Table 1.
Sanidine, Mte. Amiata, Barth analyst.

SiO ₂	63.66
TiO ₂	0.08
Al ₂ O ₃	20.29
Fe ₂ O ₃	0.13
MgO	trace
BaO	trace
CaO	0.51
Na ₂ O	2.48
K ₂ O	12.59
H ₂ O	0.32
Sum.....	100.06
Or	74.5
Ab.....	21.0
An.....	2.5
Balance	2.0

adopted. It would seem that in most of the analyses by Williams the alkali determinations are too high. Due to this error an apparent deficiency of silica will appear in the feldspars, a circumstance responsible for the old assumption that the Mte. Amiata feldspars were chemically anomalous. A new analysis by me on typical sanidine phenocrysts shows them to be normal in all respects. The analysis is quoted in Tab. 1. Occurring together with sanidine are plagioclase crystals which also have been analyzed by Williams. Careful measurements on a Fedorov stage show them to be labradorite of composition 62 An, in good agreement with Williams' analysis. The mode of occurrence of these two feldspars as phenocrysts in the same rock, often in direct contact with each other leaves no doubt as to their simultaneous crystallization from a common magma with which both of them were in equilibrium.

2) Feldspars from oligoclase trachyte, Ölberg.

3) Feldspars from oligoclase trachyte, Perlenhardt, Siebengebirge. These rocks have been described by various authors¹ as more or less fine-grained with large phenocrysts of oligoclase and sanidine. New determinations of the chemical composition of the oligoclases

¹ P. Grosser, Trachyte des Siebengebirges, Tschermak Min. Petr. Mit. 13, 39. vpm Rath, Trachyt von Perlenhardt, Zeit. deutsch Geol. Ges. 27, 1875, 329. Zirkel, Petrographie II, p. 381.

Rosenbusch, Massige Gesteine II, p. 594.

were made optically with a Fedorow stage (plotted in Fig. 3), and new alkali determinations were made on the sanidines. The results are entered in Tab. 2. It may be added that the position and the shape of the optical indicatrix of the oligoclases are quite normal, indicating that the feldspars strictly belong to the plagioclase series (potash-free). The analyses of the sanidines show the maximum content of the An-molecule to be 6—8 %; it probably is much less since

Table 2.

	I	II
Na ₂ O	4.22	4.46
K ₂ O	9.89	9.27
Or	58.4	54.7
Ab	35.5	37.7

I. Sanidine from Oligoclase Trachyte, Ölberg, Barth analyst.

II. Sanidine from Oligoclase Trachyte, Perlenhardt, Siebengebirge, Barth analyst.

the analyzed material could not be obtained absolutely pure, but most likely contained small amounts of water and other impurities.

4) Feldspars from trachyandesite, Ragged Mt., Gunnison Co., Colorado. This rock has been described by Cross.¹ It contains very large phenocrysts of alkali feldspar, frequently 5—8 cm long. Large crystals of plagioclase are also present. Although it is probable that the two feldspars are simultaneous, the sequence of crystallization in this rock cannot be deduced with certainty from its structural features. Measurements with the Fedorov stage showed the plagioclase to contain 40 An. A chemical analysis of the alkali feldspar has been made by Spencer.² New alkali determinations were made by me. The results are entered in Tab. 3.

5) Feldspars from biotite-hornblende rhyodacite, Mt. Konati, California. The rock has been described and an analysis published by

¹ W. Cross, Lacolithic Mountain Groups in Colorado etc. U. S. Geol. Survey Ann. Rep. 14₂, 1892—93, p. 165.

² E. Spencer, A contribution to the study of moonstone from Ceylon and other areas, and of stability relation of alkali feldspar. Min. Mag. 22, 334, 1930.

Table 3.

	I	II
Na ₂ O	2.78	2.74
K ₂ O	11.38	11.74
Or		72.9
Ab		24.1
An		3.0

I. Alkali feldspar from trachyandesite, Ragged Mt., Gunnison Co., Colorado, Barth analyst.

II. Alkali feldspar, E. Spencer analyst. (Spencer has given a complete analysis of the feldspar; in this table only the alkali determinations have been quoted.)

Anderson.¹ The rock shows phenocrysts of quartz, sanidine, oligoclase partly intergrown with augite, basaltic hornblende, and biotite. The groundmass consists of feldspar microliths and cryptocrystalline or glassy matrix. The phenocrysts being too small for hand-picking had to be separated by heavy liquids. Two fractions were obtained: One fraction containing sanidine, another containing oligoclase plus quartz. Chemical analyses were made of the two fractions. The results are presented in Tab. 4.

Table 4.

	I	II
CaO	n. d.	5.24
Na ₂ O	4.28	8.10
K ₂ O	8.72	0.98
Or	51.7	5.6
Ab	36.2	68.4
An	-	25.9

I. Sanidine from biotite-hornblende rhyodacite, Mt. Konati, California, Bruun analyst.

II. Plagioclase from the same rock, Bruun analyst.

¹ C. A. Anderson, Volcanic history of the Clear Lake Area, California. Bull. Geol. Soc. Am. 47, 629, 1936.

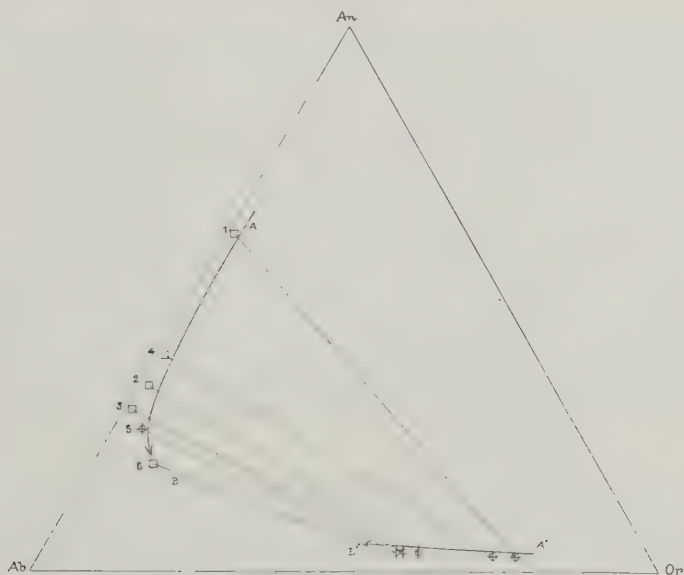


Fig. 3. Composition of various feldspars from volcanic rocks. Feldspars from the same rock, and thus in mutual equilibrium during crystallization, are connected with lines.

- 1 = Feldspars from Mte. Amiata.
- 2 = " " Ölberg, Siebengebirge.
- 3 = " " Perlenhardt, Siebengebirge.
- 4 = " " Ragged Mountain.
- 5 = " " Mt. Konati.
- 6 = " " Marquesas Islands.

⊕ designates complete chemical analysis, ⊙ incomplete analysis, · designates that composition is calculated from rock analysis, and □ from optical analysis.

6) Feldspar from trachyte, Marquesas Islands. This rock has previously been described by me.¹ The amount of dark minerals is extremely small, only about 5%. The composition of the feldspar phases can therefore be calculated with rather great accuracy from the rock analysis. Oligoclase contains about 20 An, and Fedorov measurements indicate that some but not much potash is present in solid solution. The alkali feldspar is a soda orthoclase of the following composition:

50 Or, 45 Ab, 5 An.

A graphical survey of all the feldspar determinations so far communicated is given by the diagram, Fig. 3.

¹ T. F. W. Barth, Mineralogical Petrography of Pacific Lavas, Am. Jour. Sci. 27. 523. 1931.

In this diagram feldspars from the same rock and thus presumably in equilibrium with each other at the time of crystallization are connected with lines. The diagram clearly demonstrates that calcic plagioclase is in equilibrium with potassic sanidine, and sodic plagioclase with sodic sanidine. It thus follows from the diagram that the alkali feldspars form a reaction series from potassic to sodic analogous to the reaction series of the plagioclases from calcic to sodic (the series from A' to B' parallels the series A — B), and that the residual liquids will trend towards a point on the Or—Ab join, the composition of which may be somewhat different for the different rocks depending on composition and geological environment, but which generally speaking must be in the neighbourhood of an alkali feldspar containing about 40 % of the Or-molecule.

In this connection certain studies on Pacific lavas by myself may be mentioned (op. cit. p. 398). It was demonstrated that in all these lavas the residual liquids produced by fractional crystallization tended toward a composition of about 50 Or, 50 Ab ($\pm$ SiO₂), after which a last precipitation of a homogeneous mix-crystal of feldspar of that composition took place.

The exact shape of the fusion surface of the field of the orthoclase solid solutions has not yet been fully determined in artificial melts. In an earlier paper Bowen¹ discusses the possibilities of a reaction relation between orthoclase and anorthite vs. a eutectic relation. The results of the above petrographic studies, which essentially verify and supplement those by Terzaghi² seem to indicate a eutectic relation.

All feldspars thus far considered have been taken from unaltered volcanic rocks, and no reasonable objection can be raised to the assumption that the pristine chemical composition has been preserved. Feldspars from deep-seated rocks are different, however. Here the perthites are universally met with, and it is a well-known fact that for certain kinds of perthitic lamellæ a replacement origin must be considered. Using the criteria discussed by Andersen³ it is theoretic-

¹ N. L. Bowen, *Evolution of Igneous Rocks*, p. 230.

² Ruth Doggett, The orthoclase-plagioclase equilibrium diagram, *Jour. Geol.* 37, 712, 1929.

Ruth Doggett Terzaghi, Origin of the potash-rich rocks, *Am. Jour. Sci.* 29, 359, 1935.

³ Olaf Andersen, The genesis of some types of feldspar from granite pegmatites, *Norsk Geol. Tidsskr.* 10, 116, 1928.

tically possible by microscope studies to determine the composition and amount of the lamellæ of replacement origin, and by application of this correction calculate the pristine composition of the feldspar. Actually this is not so easy. Partly because of gradation of different types of lamellæ into one another, partly because of an uneven distribution, the results are rarely quantitatively reproduceable. It can be shown, however, that the corrections to be applied to the feldspars to be mentioned in the sequel are insignificant. In the following discussion the data of the chemical analyses are therefore directly used. This means that the original composition of the microcline perthites might have been slightly more albitic than given in Fig. 4.

Several feldspars of granitic pegmatites and coarse granites were selected for studies.

1) Feldspars from pegmatite, Frøyna. This pegmatite has been studied by Olaf Andersen (op. cit. and Norges Geol. Undersøkelse No. 128 b, 1931). The dike consists of quartz, microcline-perthite, andesine and mica. The composition of the feldspar phases are entered in Fig. 4.

Table 5.

	I	II
SiO ₂	57.35	65.55
Al ₂ O ₃ *.....	28.02	18.98
MgO.....	0.11	0.03
CaO.....	7.09	0.13
Na ₂ O.....	6.02	2.20
K ₂ O.....	1.10	13.11
H ₂ O at 105.....	0.09	-
H ₂ O.....	0.70	0.07
	100.48	100.07
Or.....	6.5	80.1
Ab.....	50.9	19.2
An.....	35.1	0.7
Balance.....	7.5	-

* Including FeO = 0.18

- I. Plagioclase from pegmatite, Berø, Bruun analyst.
- II. Microcline from pegmatite, Berø, Quoted after O. Andersen, Op. cit.

2) Feldspars from pegmatite, Berø. An analysis of the pegmatite is given by Olaf Andersen (op. cit.) who also has studied the accompanying minerals. A new analysis of the plagioclase is entered in Tab. 5. The composition of the feldspar phases is given graphically in Fig. 4.

3) Feldspars from pegmatitic granite, Stjernøy. Like the preceding rock this represents a pegmatitic facies of the South Norwegian gneiss formation. It contains quartz, microcline-perthite, and plagioclase. New chemical analyses of the microcline-perthite and of the plagioclase are quoted in Tab. 6, and graphically presented in Fig. 4.

Table 6.

	I	II
SiO ₂	63.18	64.07
Al ₂ O ₃	24.00*	20.68
MgO.....	0.03	0.13
CaO.....	3.12	0.30
Na ₂ O.....	8.77	2.66
K ₂ O.....	0.87	12.49
Los on ign.	0.16	n. d.
	100.13	100.33
Or.....	5.1	73.7
Ab.....	74.0	22.5
An.....	15.5	1.5
Balance.....	5.4	2.3

* Including FeO = 0.26.

I. Plagioclase from Stjernøy, Bruun analyst.

II. Microcline from Stjernøy, Bruun analyst.

4) Feldspars from pegmatite, Risøen. This rock has been studied by Olaf Andersen (op. cit.). The predominant minerals are plagioclase and quartz; in addition microcline-perthite, green pyroxene, and biotite occur. Chemical analyses have been published of both feldspar phases. The compositions are graphically plotted in Fig. 4.

Fig. 4 gives a graphical survey of the feldspar determinations; feldspars from the same rock are connected with lines. Fig. 4 resembles Fig. 3. It is again seen that the more calcic the plagioclase the more potassic the orthoclase solid solution with which it is in

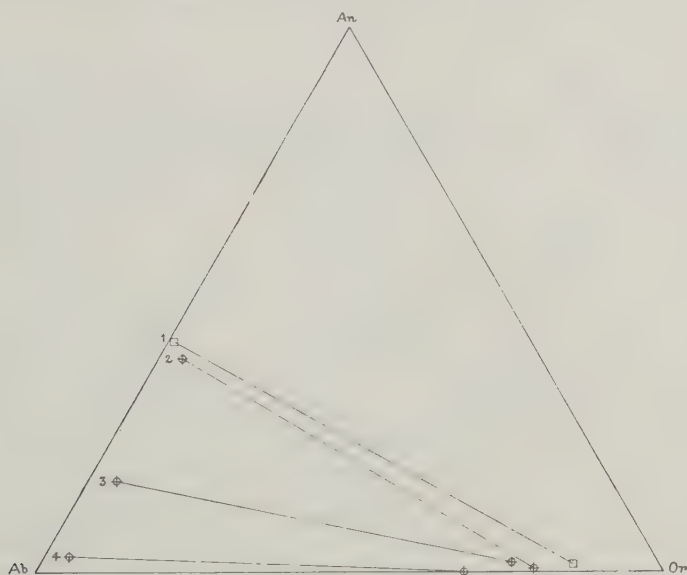


Fig. 4. *Composition of various feldspars from pegmatitic rocks.*
Feldspars from the same rock and thus in mutual equilibrium during crystallization are connected with lines.

- | | | |
|-----|----------------|-------------|
| 1 = | Feldspars from | Frøyna. |
| 2 = | " | " Berø. |
| 3 = | " | " Stjernøy. |
| 4 = | " | " Risøen. |

Symbols as in Fig. 3.

equilibrium. The conclusions from p. 186 are thus verified: In deep-seated rocks also orthoclase solid solutions form a reaction series from potassic to sodic keeping pace with the plagioclase reaction series.

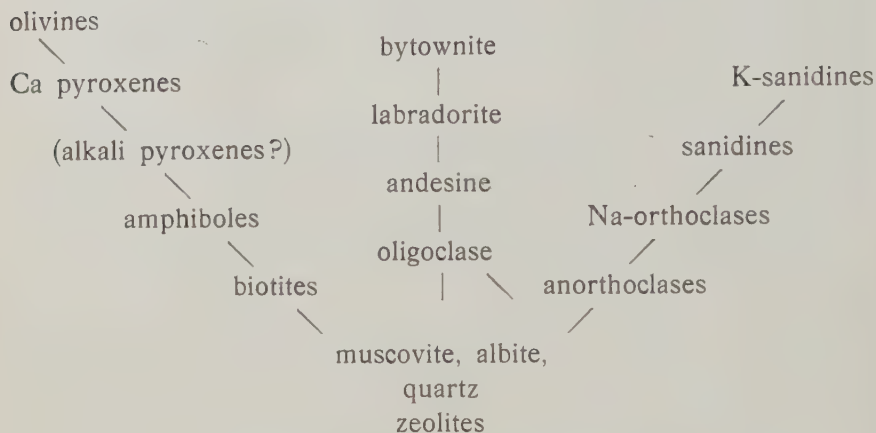
C. Conclusions.

It is the merit of Bowen¹ to have demonstrated and pointed out the fundamental importance of reaction series in petrology. He has arranged the minerals of the ordinary sub-alkaline rocks as reaction series consisting of two branches converging upon potash feldspar.

The results of the present investigation indicate that in certain rock magmas the reaction series of the alkali feldspars should be recognized in addition to that of the plagioclases.

¹ N. L. Bowen, The reaction principle in petrogenesis, Jour. Geol. 30, 177, 1922.

This is graphically indicated below:



In a recent paper Bowen (op. cit.) has pointed out that in fractional crystallization of silicate melts resembling "average" magmas the bulk of the plagioclase and ferromagnesian minerals will separate before the alkali feldspars start to crystallize. Under such conditions no great importance can be attached to the series of the alkali feldspars. However, sanidines are early crystallization products in some specialized potash-rich magmas, as demonstrated by the present observations, and in such magmas the reaction series of the alkali feldspars becomes of great consequence for the further magmatic development. With special reference to such rocks it would seem justified to place the beginning of this reaction series on level with that of the plagioclases.

*Mineralogisk institutt Oslo,
September 1937.*

DER HISTOLOGISCHE AUFBAU DER ANASPIDEN-SCHUPPEN

VON
WALTER GROSS

MIT 1 TEXTABBILDUNG UND 2 TAFELN

Die nachfolgend beschriebenen Dünnschliffe von Anaspiden-Schuppen aus dem norwegischen und englischen Downton erhielt ich von Dr. A. Heintz mit der Bitte, sie zu untersuchen. Damit sollte eine ursprünglich von dem verstorbenen Professor J. Kiær geplante Arbeit ausgeführt werden. Die Dünnschliffe und die hier wiedergegebenen Mikrophotographien hat noch Prof. Kiær herstellen lassen. Das Material gehört dem Palaeontologisk Museum in Oslo. Herrn Dr. A. Heintz danke ich für das Angebot, dieses Material aus dem Nachlass von Prof. Kiær zu untersuchen.

In den letzten Jahren ist der histologische Aufbau des Skelettes fast aller silurischen und devonischen Agnathen und Fische erforscht worden (Stensiø, Gross, Heintz u. a.) mit Ausnahme der Anaspiden. Eines der wichtigsten Ergebnisse dieser Untersuchungen war die Feststellung, daß die verschiedenen Stämme der Agnathen und Fische vielfach einen so charakteristischen Feinbau ihrer Panzer und Schuppen aufweisen, daß man auf Grund von Dünnschliffen die Zugehörigkeit eines isolierten Knochenrestes zu einer bestimmten Ordnung oder Unterklasse dieser Wirbeltiere leicht feststellen kann. So stellen in dieser Beziehung die Cephalaspida einen ganz bestimmten Typus dar, die Pteraspida einen anderen, einen weiteren die Coelolepida u.s.w. Nun interessiert natürlich die Frage, welchem histologischen Typus die Anaspida angehören, und ob sie auch hierin ihre Zugehörigkeit zu den Cephalaspidomorphi erkennen lassen.

Angaben über den Feinbau der Anaspiden-Schuppen finden sich in der Literatur sehr spärlich, wie die nachfolgenden Zitate aus Traquair (1898) und Kiær (1924) zeigen. Traquair schreibt: „Nevertheless, the structure of the substance forming the dermal scales of *Birkenia* shows neither the bone lacuna of the Osteostraci nor the dentine tubules of the Heterostraci, but so far as I have been able

to examine them microscopically, nothing is seen but a homogenous or slightly fibrillated mass, though this may possibly be the result of faulty preservation.“ Kiær bemerkt: „There is of course a possibility that the dermal skeleton of the Anaspida was extremely simply constructed without bone cells, as is the case with the chief mass of the dermal skeleton of Pteraspidae, but it is doubtless more probable that the original structure has disappeared.“

Das Fehlen von Knochenzellen und Dentinröhrchen, die Anwesenheit von Fasern und ein sehr primitiver, an die Basalschicht der Pteraspida erinnernder Bau der Anaspiden-Schuppen wurden beobachtet.

Das von Prof. Kiær zur Klärung der offenen Fragen beschaffene Material umfaßt Querschliffe durch den Körper, bezw. Schuppenpanzer des norwegischen Anaspiden *Pterolepis* Kiær und Querschliffe durch isolierte Schuppen eines nicht näher bestimmten Anaspiden aus den *Auchenaspis*-Schichten des Downtons der Umgebung von Ledbury (Baggeridge) in Südwaes. Nach brieflicher Mitteilung von W. W. King an Prof. Kiær liegt die Fundschicht ca. 450 Fuß über dem Ludlow Bone Bed. Die Entdeckung der Anaspiden-Schuppen im Gestein dieser Schichten hat Prof. Kiær bei einer Durchsicht der Sammlung von W. W. King gemacht.

Der Erhaltungszustand des Feinbaues ist an dem sonst so vorzüglich erhaltenen norwegischen Material sehr ungünstig; es lassen sich kaum irgendwelche Strukturen in den fast homogen gewordenen Schuppen erkennen. Wesentlich günstiger sind einige der englischen Anaspiden-Schuppen erhalten, die vermutlich zu *Birkenia* Trqu. gehören. Ihre Einbettung in einen roten Sandstein hat eine gewisse Färbung der feinen Strukturen hervorgerufen. Nach Beschaffung von reichlicherem Material würden sich sicher noch günstiger gefärbte Schuppen auffinden lassen.

Das englische Material ist aber auch deswegen wichtig, weil es neben den Anaspiden-Schuppen sehr zahlreiche Cephalaspiden-Schuppen, *Thelodus*-Schuppen, *Acanthodier*-Schuppen und *Onchus*-Stacheln enthält. Da bei diesen Schuppen zum größten Teil der Feinbau (Knochenzellen, Dentinröhrchen, Blutgefäßkanäle und Schleimkanäle) aufs beste erhalten ist, so ist das Fehlen dieser Elemente in den Anaspiden-Schuppen nicht eine Folge des Erhaltungszustandes, sondern eine Struktureigentümlichkeit.

Den morphologischen Bau der Schuppen veranschaulichen die Abb. 1 und die Fig. 1 der Taf. 1. Die englischen Anaspiden-Schuppen

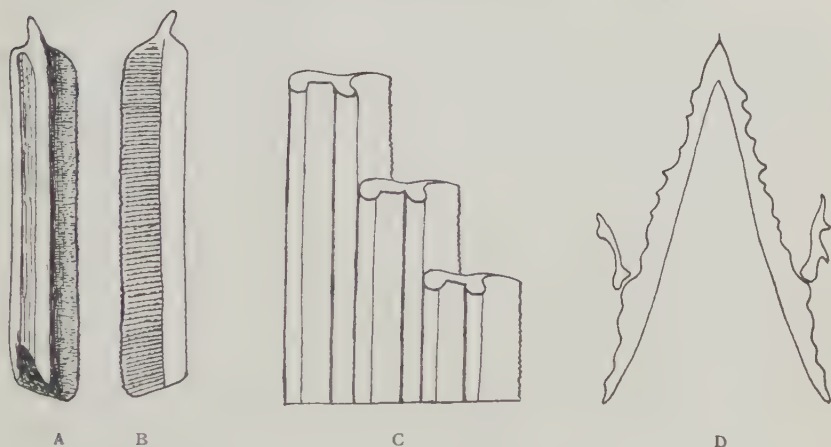


Abb. 1.

Schuppen von *Pterolepis*. A. Innenseite; B. Außenseite; C. Schematische Darstellung dreier Schuppen von der Innenseite; D. Dorsalstachel, Rekonstruktion. (A. u. B. $\times 5$, C. $\times 8$, D. $\times 20$).

Aus Kiær 1924.

werden bis 22 mm lang, 1,5 mm breit und 0,5 mm dick, stehen also in keiner Beziehung hinter den Ausmaßen der Cephalaspiden-Schuppen aus derselben Schicht nach. Ihre Oberseite ist ebenso wie bei den Schuppen von *Pterolepis* mit rundlichen Tuberkeln verziert.

Die meisten Schiffe haben die Schuppen nicht genau senkrecht, sondern schräg getroffen. Die Tuberkeln der Schuppen-Oberseite ermöglichen leicht eine Orientierung der im Gestein eingeschlossenen und durch den Schliff getroffenen Schuppen. Abweichend gestaltet sind nur die medianen Dorsalschuppen von *Pterolepis* (vergl. Kiær 1924, Fig. 28).

Die genaue Untersuchung aller Schiffe führt zu folgenden Ergebnissen. 1) Den Anaspiden-Schuppen fehlt der an den Knochen der meisten Agnathen und Fischen vorhandene Aufbau aus drei Schichten (Oberschicht, spongiöse Mittelschicht und Basalschicht) vollständig. Die Schuppen weisen einen durchgehend einheitlichen Bau auf. 2) Jede Spur von Knochenzellen und Dentinröhrchen fehlt. 3) Schmelz ist nicht vorhanden. 4) Blutgefäßkanäle finden sich nur spärlich und zwar unter den Tuberkeln, ohne aber ein verzweigtes System zu

bilden. In den meisten Querschliffen beobachtet man sie überhaupt nicht. 5) Die Schuppen sind erfüllt mit meist recht regelmäßig angeordneten Fasern. Die Fasern erfüllen teilweise den Knochen durchweg in gleicher Richtung, so daß sich Zonen gleichgerichteter Fasern bilden, was man besonders auch unter gekreuzten Mikroskopen wahrnehmen kann. In der Länge und Dicke entsprechen diese Fasern den Fasern in der Basalschicht und der Spongiosa der Psammosteiden-Panzer. Bei den Anaspiden sind sie auffallend regelmäßig angeordnet, so daß sie in bestimmten Regionen, z. B. an der Unterseite, an Dentinröhrchen erinnern (Taf. 2). Es handelt sich aber um keine Dentinröhrchen, da sie weder aus einer Pulpahöhle oder aus Blutgefäßkanälen ausstrahlen, noch sich am Ende büschelförmig auflösen oder Seitenzweige aussenden. Ferner ist ihre Anordnung zu dicht, und sie erfüllen den Knochen zonenweise, was beim Dentin nicht der Fall ist.

Obgleich die Anaspiden-Schuppen an Größe und Dicke keineswegs hinter den Schuppen der Cephalaspiden nachstehen, weisen sie nichts von den Differenzierungen auf, die für die Cephalaspiden typisch sind. Sie sind äußerst einfach gebaut, viel einfacher als die Skeletteile der übrigen bekannten altpaläozoischen Agnathen und Fische. Es ist nicht ausgeschlossen, daß ursprünglich Knochenzellen am Aufbau der Schuppen beteiligt gewesen sind, um noch während der Verknöcherung restlos zu verschwinden. Dieser Vorgang ist ja heute bei den meisten Knochen der Knochenfische anzutreffen.

Das Gewebe der Anaspiden-Schuppen ist als ganz primitiver Faserknochen ohne Knochenzellen zu bezeichnen, ein Knochengewebe, das sich an allen Wachstumszonen und Nähten der Wirbeltier-Knochen findet, besonders häufig bei kleinen Wirbeltieren.

Das Gewebe der Anaspiden-Schuppen erinnert am meisten an den Faserknochen der Psammosteiden, dem ebenfalls Knochenzellen gänzlich fehlen. Auf diese Ähnlichkeit hat bereits Kiær hingewiesen. Trotzdem die Anaspiden-Schuppen ganz anders aufgebaut sind als die Cephalaspiden-Schuppen, ist an der Verwandtschaft der morphologisch so vielfach übereinstimmenden Ordnungen nicht zu zweifeln. Man braucht nur an die Verschiedenheit des histologischen Baues der Schuppen bei den nahverwandten Osteolepiden, Rhizodontiden und Holoptychiiden zu denken oder an die Unterschiede im Schuppenbau der Holostei und Teleostei.

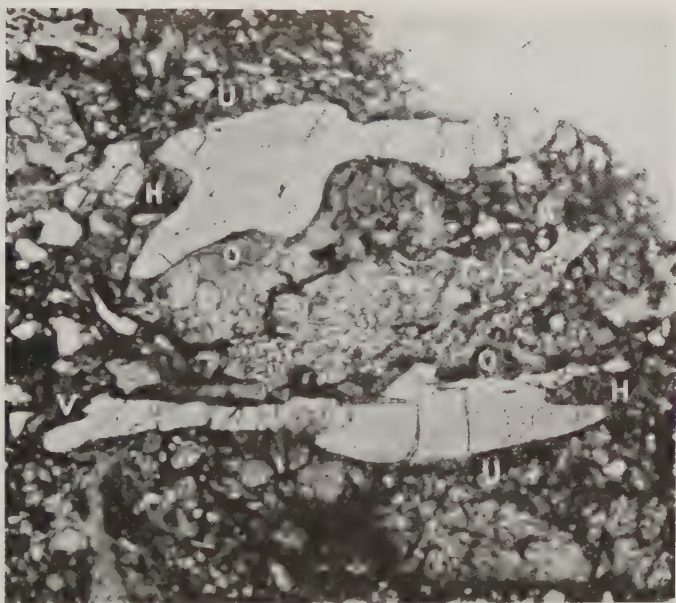
Da das Material, das zur Verfügung stand, nur wenige Schuppen umfaßte, ist die Möglichkeit, daß andere Anaspiden-Arten bei günstigerer Erhaltung einen differenzierteren Bau aufweisen, nicht endgültig von der Hand zu weisen. Andererseits spricht aber die Übereinstimmung zwischen dem norwegischen und dem englischen Material dafür, daß der geschilderte Feinbau der Schuppen für die Anaspida typisch ist.

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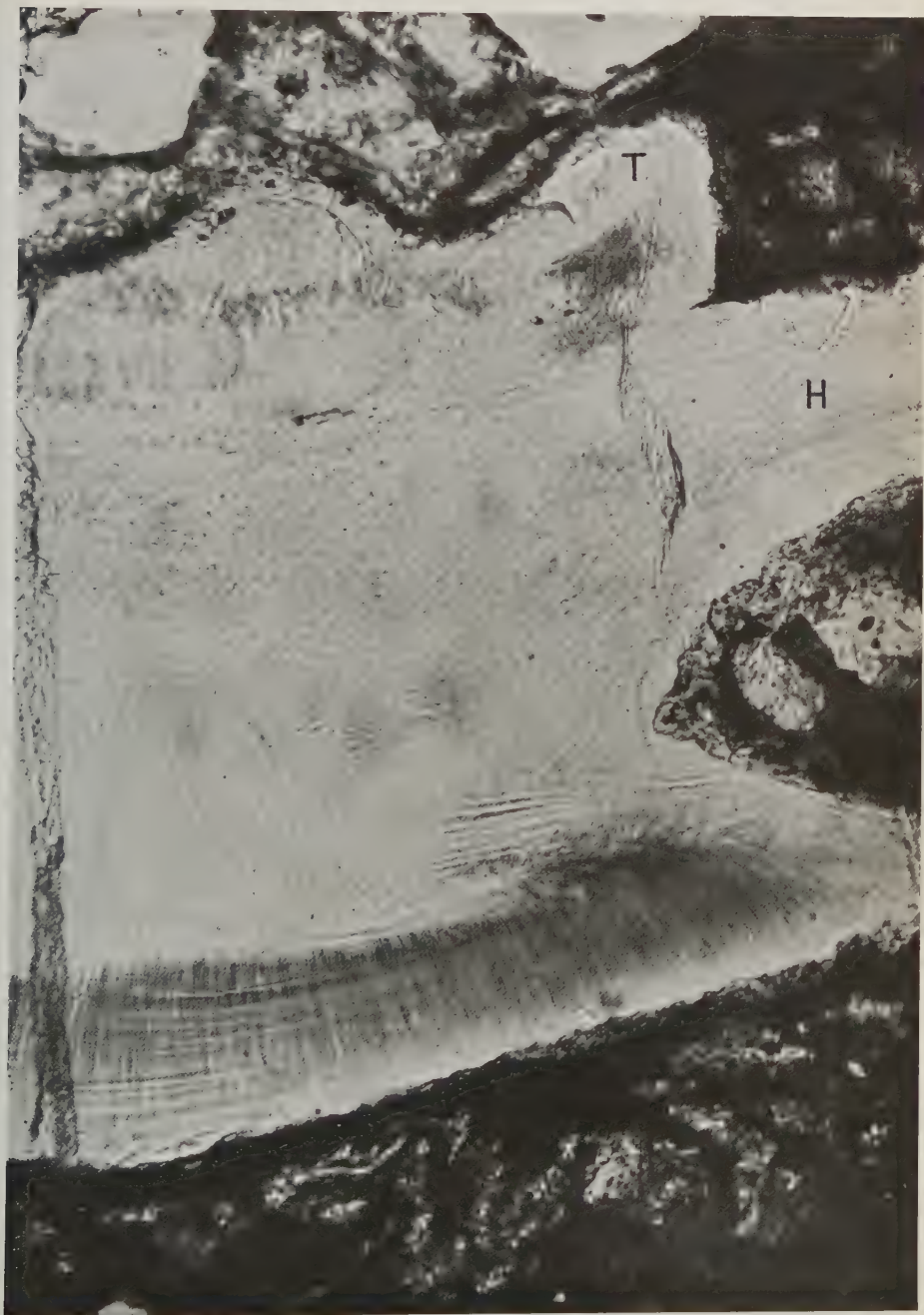
Tafel 1.

- Fig. 1. Anaspiden- (*A*) und Cephalaspiden- (*B*) Schuppen im Gestein.
Downton von Baggeridge, Südwaes. $\times 3$. Dr. L. Størmer, phot.
- Fig. 2. Schräger Querschliff durch zwei Anaspiden-Schuppen aus
Baggeridge. *H* = Hinterrand, *V* = Vorderrand, *O* = Oberseite,
U = Unterseite. $\times 20$. Dr. L. Størmer, phot.



Tafel 2.

Schräger Querschliff durch den Hinterrand einer Anaspiden-Schuppe aus Baggeridge, Südwales. $\times 310$. F = regelmäßig angeordnete Fasern, H = Hinterrand der Schuppe, die den Vorderrand der folgenden Schuppe überlagert, T = Tuberkel der Oberseite. Dr. L. Størmer, phot.



DIE VERWITTERUNG DER URANMINERALIEN

VON

ERNST FØYN

Die Arbeit der verschiedenen Untersuchungen der radioaktiven Gesteine erfordert immer eine genaue chemische Analyse derselben, nicht nur um die allgemeine Zusammensetzung des Minerals zu bestimmen, sondern auch, weil man infolge des Atomzerfalls die Möglichkeit hat, einen Begriff über das annähernde Alter des Minerals zu bekommen.

Die meisten radioaktiven Minerale tragen aber mehr oder weniger ausgeprägt Spuren einer sekundären Umwandlung, hervorgerufen durch den Verwitterungsprozeß des Minerals.

So sind die sekundären Mineralprodukte durch Umwandlung eines primären Minerals gebildet, und haben daher oft einen inneren Kern von frischer, unveränderter Ursubstanz. Auch Minerale, wie Cleveit zum Beispiel, können auf der Oberfläche einen grünen, roten oder gelben Überzug aus Verwitterungsprodukten haben, der in tiefe Spalten des Minerals eindringen kann.

Vor jeder Analyse eines radioaktiven Minerals werden diese Umwandlungsprodukte sorgfältig entfernt, so daß das zur Analyse kommende Mineral ein einheitliches Material bildet. Die Frage ist aber, in welcher Weise die sekundären Minerale entstanden sind. Sind sie durch allmähliche Verzehrerung des primären Minerals von außen ohne tiefere Eingriffe, oder sind die sekundären Umwandlungsprodukte durch irgendwelche Auswaschungsprozesse des primären Minerals gebildet.

Im ersten Fall kann man annehmen, daß die Analyse nach Entfernung des äußeren Belags immer die richtigen Verhältnisse der radioaktiven Substanzen angeben wird. Sind aber die sekundären Minerale durch Auswaschen gebildet, könnte die Analyse keine wahre Verhältniszahl angeben und man ist gezwungen, um annähernd richtige

Resultate zu bekommen, sein Ausgangsmaterial nur unter Mineralen auszusuchen, die so wenig wie möglich angegriffen sind.

Diese wichtige Frage der Mineraluntersuchung ist bis jetzt aber nur wenig behandelt worden. Es liegen zwar eine Reihe von Analysen sekundärer Minerale vor. Da aber die sekundären Minerale in noch höherem Grad als die primären für den Angriff der Atmosphärien oder die Auswaschungen ausgesetzt sind, können Analysen von ihnen keine Antwort geben. Es gibt aber auch einige experimentelle Untersuchungen. Spitzin¹ zeigte 1927, daß Radiumemanation von fließendem Wasser aus den Mineralen entfernt wurde und Salzlösungen noch effektiver als reines Wasser befunden wurden.

Eine fortwährende Auslaugung des Minerals von Emanation bedeutet, daß die radioaktiven Folgeprodukte — das Radioblei — vom Mineral entfernt werden.

Auch andere haben ähnliche Verhältnisse gefunden. Baili² hat einige Experimente mit künstlich hergestellten Blei-Uran-Verbindungen ausgeführt und es hat sich gezeigt, daß das Blei unter Kochen mit destilliertem Wasser ausgelaugt wurde.

Andere haben versucht, durch Analysen verschiedener Schichten eines Einzelkristalls zu untersuchen, ob die Mengenverhältnisse der radioaktiven Substanzen in den verschiedenen Schichten des Kristalls variieren. Alter,³ Hecht,⁴ Gleditsch und Bakken⁵ haben auch kleine Variationen gefunden. Das Gebiet ist aber lange noch nicht erforscht.

Unter Berücksichtigung, daß die Faktoren, die bei der Verwitterung mitwirken, das Wasser zusammen mit dem Sauerstoff und der Kohlensäure der Luft sind, habe ich versucht, die Verwitterung künstlich nachzumachen. Kleine Stückchen eines Minerals wurden in einem Glasrohr mit einigen Tropfen Wasser in gewöhnlicher Luft eingeschmolzen. Die Rohre wurden eine Zeitlang im Bombenofen erhitzt.

Es gelang in dieser Weise einen Angriff des Minerals zu bekommen, der ähnlich der natürlichen Verwitterung war. Die in dieser Weise gebildeten sekundären Produkte konnten leicht abgekratzt und analysiert werden.

¹ Chem. Zentralbl. 1927 (2), 2442.

² Phil. mag. 7, 4, 1927.

³ Zeitschr. f. Analyt. Chemie. B. 106, H. 3, p. 82.

⁴ Science 82, 464, 1935.

⁵ Mikrochimica Acta. B. 1, H. 1, 1937.

Bei diesem Versuch war es möglich, sowohl das sekundäre Produkt, wie die in der Flüssigkeit möglichen Auslaugungsprodukte, zu analysieren. Zwei verschiedene Minerale wurden in dieser Weise behandelt: Cleveit Jr. Nr. 116 und Bröggerit Jr. Nr. 39.

Cleveit Jr. Nr. 116.

Die kleine Mineralprobe, etwa 5 gr, wurde sorgfältig aus dem inneren Teil eines zerbrochenen Mineralstückes ausgewählt und sehr genau untersucht, daß keine Spur sekundärer Produkte vorhanden war. Die Mineralstücke zeigten überall eine homogene schwarze Oberfläche. Die Probe wurde, wie beschrieben, mit einigen Tropfen Wasser in ein mit Luft gefülltes Jenaer Glasrohr eingeschmolzen und im Bombenofen erhitzt.

Schon nach sechsständigem Erhitzen bei 190° zeigten die Mineralstücke Spuren eines grünen Überzugs, und nach 20 Stunden waren sie so stark angegriffen, daß es möglich war, den grünen Belag abzukratzen und zu analysieren.

Sowohl der Belag, wie das im Rohr vorhandene Wasser, wurde jedes für sich auf die wichtigsten radioaktiven Bestandteile analysiert.

Analyse des Wassers.

Pb	keine Spur nachweisbar mit H_2S
Fe	0
U	Spur nachweisbar mit K_4FeCn_6
Ra	weniger als $5 \cdot 10^{-12}$

Es ist zu bemerken, daß es unter dieser Behandlung nicht zu vermeiden ist, daß etwas Alkalisalz aus den Glaswänden ausgelaugt wird, und daß dies sich möglicherweise am Angriff beteiligen wird. Es spielt aber für das Resultat eine untergeordnete Rolle.

Analyse des grünen Belags.

Der Belag wurde sehr vorsichtig abgekratzt, um zu vermeiden, daß das primäre Mineral mitgerissen wird. Die Substanz zeigte eine rein grüne Farbe.

Das sekundäre Produkt	Das ursprüngliche Mineral
Gewicht 0.00589 gr	
Pb 12.5 ‰	12.05 ‰
Fe ₂ O ₃ 6.7 „	2.98 „
U ₃ O ₈ 77.5 „	79.02 „
Ra 1.55 · 10 ⁻⁷ g/g.	2.30 · 10 ⁻⁷ g/g.

Brøggerit Jr. Nr. 39.

Etwa 7 gr vollkommen schwarze Brøggeritkristalle wurden sorgfältig vom Gangart befreit und wie das Cleveit mit Wasser in Bombenrohr eingeschmolzen und erhitzt.

Nach zwanzig-stündigem Erhitzen bei 190° gab es noch keinen merkbaren Angriff. Die Temperatur wurde daher gesteigert und das Rohr weiter zehn Stunden bei 290° erhitzt. Die Kristalle bekamen bei dieser Temperatur einen roten Belag. Das Rohr wurde geöffnet und das Wasser wie der Belag jedes für sich analysiert.

Analyse des Wassers.

Keine Spur von Pb, Fe, U, und weniger als 5.10⁻¹² gr Ra.

Analyse des roten Belags.

Der Belag ließ sich sehr leicht abkratzen und wurde sorgfältig vom Mineral getrennt. Er ließ sich nicht in Salpetersäure lösen, aber erst nach längerer Behandlung in Salzsäure.

Das sekundäre Produkt	Das ursprüngliche Mineral
Gewicht 0.01284 gr	
PbO 30.1 ‰	9.63
Fe ₂ O ₃ 71.5 „	0.36
U ₃ O ₈ Spur	76.20
ThO ₂ Spur	7.82
Ra weniger als 5.10 ⁻¹² g.	2.22 · 10 ⁻⁷ g/g.

Es ist auffallend, wie verschieden diese beiden annähernd gleich uranhaltigen Minerale auf den Angriff reagieren. Der Cleveit ist sehr leicht angreifbar, der Brøggerit sehr schwer, und es besteht ein

großer Unterschied in der Zusammensetzung der sekundär gebildeten Produkte.

Werden die analytischen Daten dieser sekundären Produkte mit denen des primären Minerals verglichen, so zeigt sich bei dem Cleveit eine so große Übereinstimmung in der Zusammensetzung, daß man bei Berücksichtigung der Schwierigkeiten bei den Untersuchungen die Analysen als identisch ansehen kann.

Der Cleveit ist scheinbar nur von außen angegriffen. Der Prozeß ist wie eine allmähliche Verzehrung ohne Auslaugung vor sich gegangen.

Beim Bröggerit sind aber die Verhältnisse ganz andere. Das Mineral läßt sich schwer angreifen, aber wenn ein Angriff gelingt, sind die sekundär gebildeten Produkte vollkommen verschieden vom ursprünglichen Mineral. Es scheint, als ob eine Mischung von Blei und Eisen in einer Art künstlich hydrothermalen Prozeß aus dem primären Mineral gelaugt wird.

Diese Auslaugung von Blei und Eisen ist sehr interessant, denn die beiden Elemente kommen in verhältnismäßig kleinen Mengen im primären Mineral vor, aber scheint in der Natur nicht vorgehen zu können, denn so viel wir wissen, sind in der Nähe von Uranlagern nie sekundäre Minerale gefunden worden, deren Hauptbestandteile Eisen und Blei sind.

Dieses verschiedene Verhalten der beiden Minerale muß wahrscheinlich mit der Anordnung der Atome im Kristall in Zusammenhang stehen. Es ist anzunehmen, daß die Atome im Cleveitkristall so geordnet sind, daß sie eine größere und mehr poröse Oberfläche herstellen, die jenem Angriff mehr ausgesetzt ist. Derselbe Schluß, wurde übrigens nach den Studien des natürlichen Emanationsverlustes (noch nicht publiziert) erreicht. Es ist daher auch verständlich, daß das Verhältnis UO_2/UO_3 in diesen Mineralen gewöhnlich kleiner ist als in den Bröggeriten. Bröggerit $\text{UO}_2/\text{UO}_3 = 2.17$, Cleveit $\text{UO}_2/\text{UO}_3 = 0.71$.

Ein niedriges UO_2/UO_3 -Verhältnis zeigt aber noch nicht eindeutig, daß das Mineral verändert und für die radioaktiven Untersuchungen minderwertig ist, denn eben bei diesen Mineralen ist anzunehmen, daß die Angriffe der Atmosphärien von außen einwirken und das Mineral verzehren ohne irgendwelche Bestandteile in nennenswertem Grad auszulaugen. Es ist selbstverständlich nicht möglich, nach diesen wenigen Untersuchungen über die Verwitterung

etwas Generelles auszusprechen. Das Studium der hier beschriebenen künstlichen Verwitterung ist aber sehr interessant, und könnte, wenn systematische Untersuchungen durchgeführt werden können, sehr wahrscheinlich ein gutes Hilfsmittel für das Verstehen der natürlichen Verwitterung der Urangesteine schaffen.

Zusammenfassung.

Die Verwitterung der Uraniten ist diskutiert. Zwei Uranmineralien, Cleveit und Bröggerit, wurden in Bombenrohren mit destilliertem Wasser erhitzt und dadurch verwitterungsähnliche Prozesse hervorgerufen. Die künstlichen Verwitterungsprodukte sind analysiert. Die Produkte des Cleveits waren annähernd derselben Zusammensetzung wie die des ursprünglichen Minerals, während die Bröggeritprodukte nur von Eisen und Bleioxyden zusammengesetzt waren. Die Versuche werden fortgesetzt.

NOTISER

HERDLA-TRINNET

de ytterste glaciallag i Bergensfeltet.

MED 1 KARTSKISSE

En av de mest typiske moréner med terrasseinnsnitt i Bergensfeltet er Herdla-morénen.

For enden av den 17 km lange, 1—2 km brede og over 400 m dype Herdleffjord ligger øen Herdla, som i dette ellers nakne kystlende utmerker sig ved å ha en mengde løsmateriale. Øens østlige del er en flat sandslette, Valen, omtrent 3 m o. h., og den vestlige del, som formentlig består av hårdere berg, har terrasseinnsnitt på 11,0 og 28,2 m høide, således som offentliggjort av C. F. KOLDERUP¹ i 1907. Løsmateriale fins i en høide av omkring 50 m, men her er terrasseflatene noget mindre sikre.

Grusen på Herdla er ikke særlig grov, men stranden med de mange utvaskede store blokker synes allikevel å tyde på at den er morénegrus.

Herdleffjorden er geologisk en fortsettelse av den indre eller centrale bue av kambrisk-siluriske bergarter, og iallfall langs dens sydvestside kan man følge glimmerskifer nesten helt ut til Herdla. Her har således vært fortrinlige betingelser for erosjon.

Når Herdleffjorden overhode kan brukes for gjennomgående trafikk, skyldes det et tversgående sund, Det Naue, som fører ut i Sætreosen og Flaket.

I Nordhordland går en rekke fjorder parallell Herdleffjorden, således Radfjorden med Mangerfjorden, Radsundet, Lurefjorden med Seimsfjorden og Austfjorden med Fjensfjorden.

Under arbeidet med berggrunnskartlegningen av Bergensfeltet blev det også søkt efter glacialavsetninger som ligger på samme måte som de på Herdla, idet det måtte ansees rimelig at et slikt tydelig trin i isbevegelsen som markert ved Herdla også måtte etterlate spor ved de andre fjordmunninger, selv om forholdene ingen steder synes så gunstige som på Herdla.

Herdleffjordens nabofjord i nordøst, Radfjorden, har en innsnevring ved Bognøy, men hverken her eller lenger syd i fjorden fantes noget løsmateriale av betydning. Det viste sig derimot at eidet sydøst for Skjelanger har et sammenhengende, om enn tynt dekke av løsmateriale

¹ CARL FRED. KOLDERUP: Bergensfeltet og tilstødende trakter i senglacial og postglacial tid. Bergens Museums Årbok 1907 nr. 14.

med terrasseinnsnitt i. Materialet er ulaget grus med stor sten. Dertil viste det sig at alle viker på sydsiden av Skjelangerlandet har terrassert løsmateriale.

Tvers over øen Flone, nordvest for Manger ligger det en del løsmateriale noget syd for nordspissen. På den utsatte vestsida ser man utvasket morenegrus, hvor det vesentlig er store sten som ligger igjen. På østsiden er der tydelige terrasseflater. Selve gården ligger på 23 m, mens eidet over øen ligger på 9 m. Tallene er hentet fra målebordsbladene til det nye gradteigkart.

På selve Radøy er fra før kjent terrasser på Innsylta, med høider målt av C. F. KOLDERUP, til 28,5 og 10,6 m. Snitt i disse viste et delvis lagdelt grus, med optil hodestore sten.

Lensmann OTTESEN, Manger, har dessuten funnet moréner ved Bø og Villanger, nordligst på Radøy.

Moréneren ved Bø ligger på et eid mellom Hauglandsvatn og Rikstadvågen. Da Radøy er meget fattig på veigrus, og Bø-moréneren ligger like ved kjøreveien, er moréneren snart helt opbrukt.

Vilangermoréneren er som Bømoréneren en rygg i et dalsøkk.

På selve Fosnøy er der ingen tydelige terrasser, og heller ingen morénerygger. Men en stor del av det lavere land, 10—20 m o. h. er er dekket av leir, delvis jordblandet, delvis sandet, så man har temmelig store områder av glacialavsetninger her.

Ved Kjelstraumen er der på østsiden en liten flekk av løsmateriale, en utydelig terrasse. Lenger øst på Lindåshalvøen er der flere og noget mektigere masser.

Fonnes-gårdene ligger på en omtrent sammenhengende morénemasse, som strekker sig fra fjorden og sydover til en smal våg. Overflaten er nogenlunde flat.

I Leirvåg, noget østenfor, er der også litt morénemateriale. Her står Fjensfjorden på, og her er en moderne strandvoll. Syd for denne er der to høiere strandvoller, som beskytter noen større torvdekkede flater.

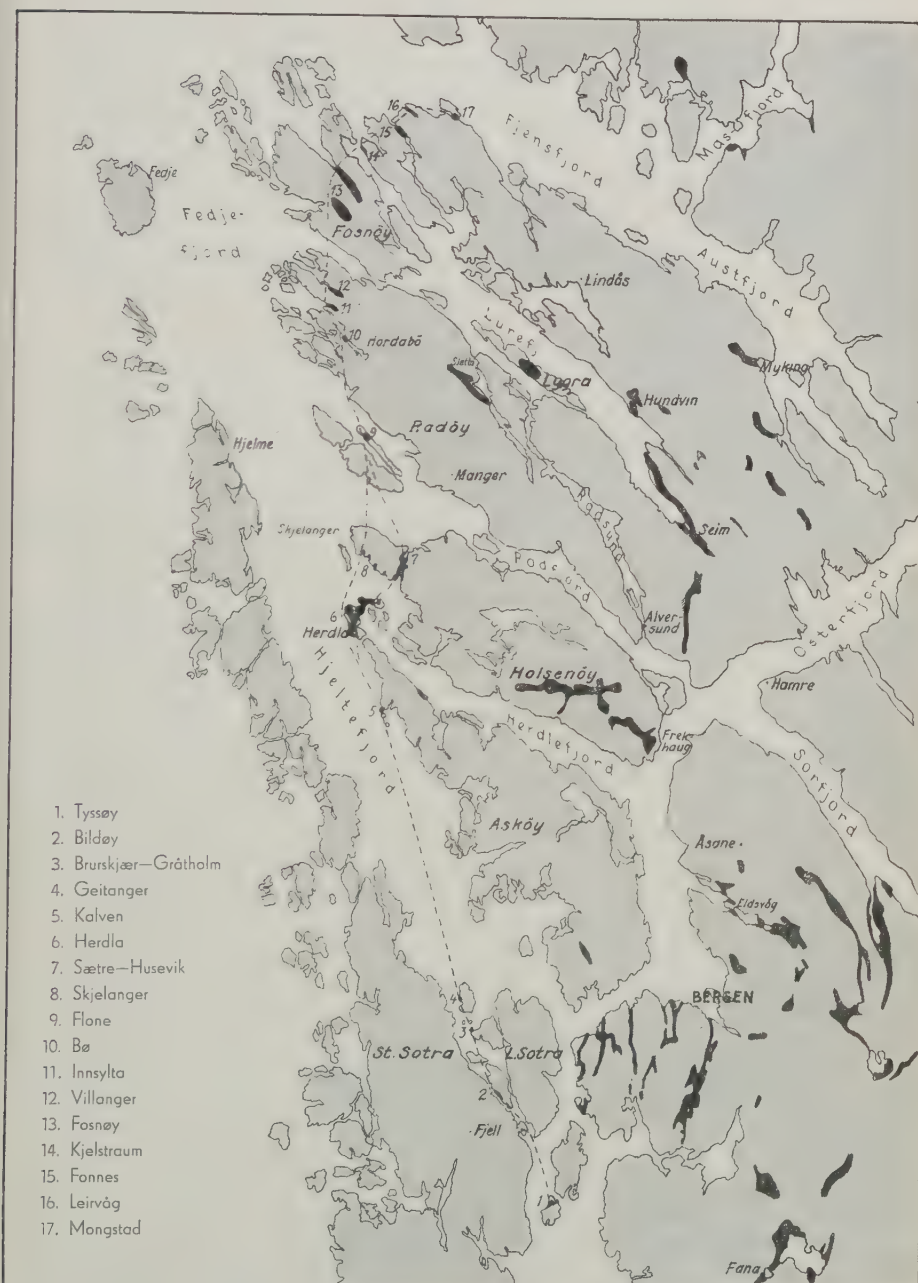
De største masser her nord ligger imidlertid på Mongstad. Det eid som gårdene ligger på, er vesentlig løsmateriale og sjøkartet viser at her er store sandmasser som grunner op viken på begge sider.

I og med disse morénemasser er der altså kartlagt en ytre rekke av moréner fra Herdla over Sætre—Skjelanger—Husebø¹ (på Holsenøy), Flone—Bø—Innsylta—Villanger (på Radøy)—Fosnøy—Kjelstraum—Fonnes—Leirvåg—Mongstad (på Lindåshalvøen).

Sydover fra Herdla er det ikke så lett å finne en sammenhengende rekke.

I en liten holme, Kalven, like ved Oksneskletten, 3—4 km syd for Askøys sydspiss, er der en liten moréne i en sprekke som går tvers over holmen. Denne behøver ikke være noget annet enn en bunnmoréne.

¹ 7. Sætre—Husevik på kartet skal være 7. Sætre—Husebø.



Ved Ågotness på østsiden av St. Sotra er der også litt løsmateriale. I strøket mellom St. og L. Sotra er der så en mengde mindre avleiringer.

Over Geitanger går to teiger, som ved stranden viser sig å være grovt morénegrus. To små skjær, Gråtholm og Brurskjær, består av vel avrundede blokker, rester av en utvasket moréne.

På østsiden av Sotra, men særlig på vestsiden av Bildøy er der grus, delvis leirholdig, i nær sagt alle dumper. Og der er en terrasseflate på Bildøy i en høide av 25 m.

På Tyssøy er der en sammenhengende terrasseflate omtrent 400 m lang, med høider på 24—26 m. Her er dessuten adskillig løsmateriale i vikene rundt øen.

Om enn sammenhengen mellom Herdla og sydover ikke er så lett å finne som nordover, er her dog en helt sikker rekke av moréner.

Det er ikke funnet morénemateriale mellom disse forekomster og havet utenfor, mens det er en mengde forekomster innenfor.

Denne rekke av moréner som er avmerket på kartet behøver selvsagt ikke være synkron. Jeg har bare funnet rekken å være så påfallende at jeg har ønsket å offentliggjøre den.

Innenfor denne rekke er der en mengde glacialavleiringer så vel vest som nord for Bergen.

Hele den halvøy som ligger sydvest for byen har store morénemasser i alle sine daler. I et dalføre som munner ut ved Eidsvåg, nord for Bergen, er der likeledes store morénemasser, delvis sammen med elvegrus og ur.

Askøy har merkelig lite løsmateriale, og nesten ingen større sammenhengende masser. En smal stripe delvis dekket av myr, fins på sydvestsiden, og en del mindre striper på nordøstsiden, langs Herdlefjord. Holsenøy har derimot meget løsmateriale i sin sydlige del. Her har C. F. KOLDERUP målt terrasser ved Fløksand på 28,2, 19,0 og ca. 5 m.

Også ved Leirvik og lenger nord ved lo er der terrasser vesentlig lavere. Alle disse ligger også ved Herdlefjord. Fra Frekhaug og vestover går et nesten sammenhengende belte av løsmateriale, og dette har på sine steder overflater som minner om terrasser. Høidene er 28—32 m og omkring 60 m. Særlig det siste er en temmelig problematisk høide.

På Radøy er der et temmelig tynt dekke av grus i Slette-bygden.

I sammenheng hermed står terrassene på Lygra. Her er ingen tilgjengelige snitt i terrassene, som efter rektangelkartet når 110 fot, altså 33—34 m. Nogenlunde tilsvarende høider forekommer også på Hundvin og Myking.

Det er imidlertid ganske påfallende hvor stor avstand der er mellom avleiringene nordligst på Lindåshalvøen og Hundvin—Myking.

Store grusmasser fins også i Seim, men her er terrassesnittene mindre tydelige.

Det lar sig selvsagt ikke gjøre å trekke nogen videre slutninger av det materiale som her er offentliggjort. Materialet måtte først bearbeides

grundigere enn det har vært anledning til hittil. Og hertil burde, som dr. KNUT FÆGRI har vært så elskverdig å gjøre opmerksom på, torvmyrene på øyene utenfor morénene undersøkes for å bringe på det rene om der fins nogen interglacialavleiringer.

Det får være nok å slå fast foreløpig at her i Bergensfeltet er funnet en rekke glacialavleiringer, vesentlig endemoréner som viser et stadium hvor isen rakk frem til Øygarden Hjeltefjorden, mens selve Øygaren var isfri. Det kan også gjentas at morénavleiringer ikke er funnet utenfor Herdla-linjen, i selve Øygaren.

Niels-Henr. Kolderup.

NORSK ARKEOLOGISK SELSKAP

Norsk arkeologisk selskap blev stiftet 23de november 1936 og hadde allerede ved den første generalforsamling 23de november 1937 5 ganger så mange medlemmer som den 45 år gamle Norsk geologisk forening.

Når interessen er så stor, må det vekke forundring, at det ikke i lang tid har været en arkeologisk forening i Norge. Av styrets redegjøring ser en også, at tanken ikke er ny.

Et arkeologisk tidsskrift fikk vi allerede i 1834 med W. F. K. Christies „Urda“, som Bergens museum utgav til 1847. Under den nasjonale strømning, som utgikk fra slike menn som I. C. Dahl blev i 1840-årenes blomstringsperiode „Foreningen til norske Fortidsmindesmærkers Bevaring“ stiftet i 1844. Den var like til slutten av århundredet under N. Nicolaysens virksomhet en arkeologisk forening og dens årbok et arkeologisk tidsskrift, som kom til å avløse „Urda“. Fra 1899 har foreningen bare tatt sig av yngre fortidsminner, og dens årbok har ikke hatt arkeologisk innhold.

I 1910 fikk de arkeologiske muséene i Oslo, Stavanger, Bergen, Trondheim og Tromsø istand et arkeologisk tidsskrift „Oldtiden“ med A. W. Brøgger som redaktør. Efter 1932 er ingenting kommet av det, og to bind ligger uten avslutning.

Et forsøk på å stifte et norsk arkeologisk selskap i 1917 førte ikke frem. Men at det hverken var interesse eller penger, det skortet på, viser det imponerende resultat av innsamlingen til Borrefondet, satt igang A. W. Brøgger. I løpet av 6 uker i februar—mars 1918 kom det inn 120000 kroner. Med tilskudd fra dette fond skulde selskapet utgi et tidsskrift med titelen „Arkiv for norsk arkeologi“. Men det blev ikke noget hverken av selskapet eller tidsskriftet.

Støttet til, at Norsk arkeologisk selskap nu endelig blev stiftet, var den internasjonale arkeologkongress i Oslo i august 1936. I april 1936 blev det utsendt opfordring om å tegne sig som stiftende medlem av Norsk arkeologisk selskap, og det meldte sig så mange, at selskapet kunde optræde som en organisasjon på kongressen. Formelt blev det konstituert 23de november 1936 og den første ordinære generalforsamling holdt 23de november 1937. Av de 487 medlemmer er 362 norske. Det store norske

medlemstal viser, at det vesentlig er interesserte utenfor fagfolkenes kreds, som holder selskapet oppe. Selskapets styre er advokat H. Bergh, formann, godseier F. M. Treschow, direktør Cato Rachlew, professor H. Shetelig og arkitekt G. Eliassen. Generalsekretær er professor A. W. Brøgger. Som sekretær og kasserer har styret valgt konservator E. S. Engelstad, Universitetets oldsaksamling, Oslo.

Samarbeidet mellom arkeologi og geologi er i Norge gjort unødig vanskelig ved at de to fag ved Universitetet er lagt under ulike fakultet. En student kan ikke kombinere dem til embedseksamen. En lærer i den høiere skole har derfor ikke gjennom sin universitetsutdannelse fått nogen oversikt over landets historie i sin sammenheng. For historielæreren vil menneskets første opptreden stå som en uklar og uforklarlig begynnelse til den „egentlige“ historie i den grå mytiske urtid, som det blir gått lettest mulig bortover, fordi læreren er på usikker grunn. Den tid, da „verdenshistorien“ begynte med den babylonske skapelsesberetning, er ikke svært langt borte. Den geologisk-arkeologisk utdannede lærer vil se det hele ikke som en begynnelse men som en fortsettelse av en naturlig sammenhengende utvikling med mennesket på sin plass i naturhistorien.

Arkeologi er naturhistorie likesom paleontologi, anthropologi, anatomi og fysiologi, fordi den behandler mennesket som naturvesen i sin almindelighet og ikke bare som intellektuelt vesen. Det er den vanlige synsmåte i andre land. Den vil bl. a. komme frem i det nye tidsskrift „Quartär. Jahrbuch für Erforschung des Eiszeitalters und seiner Kulturen“, som under redaksjon av Rudolf Grahmann, Freiberg, og Lothar Zotz, Breslau, nu begynner å utkomme hos Walter de Gruyter, Berlin.

Norsk arkeologisk selskap skal også utgi et tidsskrift. Det er selskapets nærmeste og naturligste opgave, opplyser styret. Like nært og naturlig burde det være, at selskapet tok op og førte videre det gode arkeologiske tidsskrift, vi har, „Oldtiden“. Men styret har ikke villet det så. Det har også vraket det saklige navneforslag fra 1918 „Arkiv for norsk arkeologi“. I steden har det valgt å overgi sig til maskinalderens reklamejargon og dokumentere gummiens og boksemelkens tidsalder med navnet „Viking“. Et så usaklig og misvisende navn kan bare skade tidsskriftet, og det vilde være å ønske, at det snarest mulig blev forandret.

Videre vil det være å ønske, at det kommer istand et godt samarbeid mellom Norsk arkeologisk selskap og Norsk geologisk forening.

Halvor Rosendahl.

NORSK GEOLOGISK FORENINGS VIRKSOMHET

MØTE TORSDAG 8. APRIL 1937

Tilstede 35 medlemmer og 19 gjester.

Foredrag av professor TH. VOGT: *Litt om det geologiske arbeide ved Røros*. Trykt under titelen „Undersøkelse av våre malmleier efter moderne metoder“. Tidsskr. kjemi bergv. 16, 1936 nr. 9, p. 136—140.

Representanter for Widerøes flyveselskap demonstrerte flyvefotografier.

I ordsiftet efter foredraget deltok C. O. B. Damm, Th. Vogt, C. W. Carstens, V. M. Goldschmidt, C. Bugge, A. Bugge, V. Skappel, H. H. Smith.

På grunn av det langvarige ordsifte måtte det annet foredrag av Th. Vogt: „Om dannelsen av kisleforekomstene ved Røros“ utsettes til et av møtene i høstsemestret.

MØTE TORSDAG 29. APRIL 1937

Tilstede 14 medlemmer og 16 gjester.

Programmet var:

Korte foredrag:

1. Løitnant HELGE SKAPPEL: *Flyving og luftfotografering*.
2. Cand. real. ERNST FØYN: *Forsøk med kunstig forvitring av noen uranmineraler*.
3. Konservator HARALD BJØRLYKKE: *Scheteligit, et nytt pegmatittmineral. Foreløpig meddelelse*.
4. Konservator IVAR OFTEDAL: *Om Fevik-granitten. Foreløpig meddelelse*.

På grunn av sykdom måtte Bjørlykkes foredrag avlyses. En foreløpig meddelelse om mineralet er trykt i dette bind p. 47—49.

Løitnant Helge Skappel var forhindret fra å komme, og foredraget blev holdt av cand. ocon. Vilhelm Skappel.

Foredragsholderen hevdet at vårt langstrakte land med de mange fjorder og sjøer egned sig best for sjøfly. Efter å ha omtalt årstidenes og verforholdenes innflytelse på flyvingen og fotograferingen, forklarte han fremgangsmåtene ved skrå- og vertikalfotograferinger. Han gjennomgikk de forskjellige metoder for fotogrammetrisk kartfremstilling, og forklarte spesielt de mest brukte apparater: entzerrungsapparatet, multipleks og stereografen. Til slutt kom foredragsholderen inn på spørsmålet om hvilke store muligheter flyvingen, luftfotografier og fotografiske karter vil

ha ved geologiske undersøkelser, og han fremhevet særlig de stereoskopiske vertikalfotografier som det beste arbeidsgrunnlag ved terrengstudier.

I forbindelse med foredraget demonstrerte foredragsholderen et speil-stereoskop og prøver på vertikalfotografier og arbeidskart.

I anledning foredraget fremkom uttalelser av G. Horn, S. Føyn og L. Størmer.

Cand. real. Ernst Føyns foredrag vil bli trykt i tidsskriftet, bd. 17. Efter foredraget uttalte sig H. Rosendahl, T. Barth og E. Gleditsch.

IVAR OFTEDAL: *Om Fevik-granitten. Foreløpig meddelelse.*

Foredragsholderen demonstrerte sitt kart over fjellgrunnen i Fevik-granittens område og nevnte en del resultater av de petrografiske og geologiske undersøkelser. Bearbeidelsen av bergartsmaterialet er ennå ikke avsluttet.

De bergarter som omgir Fevik-granitten hører til Bambleformasjonens sedvanlige typer av krystallinske skifre. De står innen området steilt og stryker stort sett litt vestlig av N—S, altså adskillig mere sydlig enn f. eks. ved Arendal. Granittgrensen er stykkevis knivskarp, således i begge snittene med kysten, på odden utenfor Rosseknipen og ved Plasene ved Søm. Hvor grensen er godt synlig står den steilt. De krystallinske skifre utenfor granittgrensen er for en stor del sterkt rødfarvet av den samme intenst røde alkalifeltspat som danner granittens hovedbestanddel. Granitten er på denne måte omgitt av en migmatittsone, som på sine steder kan spores inntil et par kilometer fra grensen. Migmatitten spiller især en stor rolle på vestsiden og nordsiden av granitten, således i selve Grimstad og omegn. Det viser sig at det er de løsere glimmerrike gneisbergarter som er migmatittisert, mens kompaktere bergarter som amfibolitt og kvartsitt ikke viser nogen påvirkning av granitten, selv tett inn til grensen. Migmatittdannelsen strekker sig derfor båndvis utover fra granitten i strøkretningen. Enkelte bånd er så sterkt migmatittisert at de synes å bestå av en kompakt, finkornet rød granitt bare med svake spor av parallellstruktur. Ved siden av denne migmatittdannelse har vi utenfor granittgrensen en mengde ganger, vesentlig aplittiske, som gjennomsetter gneisbergartene, også kvartsitter og amfibolitter, i forskjellige retninger. Til dels optrer disse finkornede granitter i større, uregelmessige masser, ofte med inneslutninger av gneisbergartene. Nogen av inneslutningene i disse eruptivbreksjer er næsten helt assimileret av granitten og stikker næsten ikke av mot denne. Eksempel på dette har man i den oprakende knaus Vardåsen ved Fuhrs gartneri i Grimstad. Slike klare eruptivbreksjer ser man ikke så mange steder, men i store partier som er sterkt gjennomvevet av granittganger kan man finne uregelmessige strøkretninger som tyder på at granitten under sin fremtreden har deformert og brutt op gneisbergartene. Dette fenomen er på lange stykker tett inn på hovedgranittens grense meget intenst og vanskeliggjør da en noiaktig lokalisering av grensen, iallfall kan man på disse steder ikke se den som en skarp linje. Dette gjelder det meste av granittens vest- og nordgrense. Ved den østlige grense synes både



Forenklet kart over fjellgrunnen i Fevik-granittens område, utarbeidet av Ivar Ofteidal 1937.

ganger og migmatitt å spille en mindre rolle; grensen er for øvrig her meget overdekket. Ute i sjøen går grensen tett nordenfor Ryvingen og tett sønnenfor Hesnesøya. På grunnlag av undersjøiske høidedrag faller det naturlig å trekke grensen ute i sjøen slik at hele omrisset av hovedgranitten blir ellipseformet. Fra Rosseknipen har hovedgranitten en smal utløper som strekker sig nordvestover til henimot Rønnes. Den fortsetter med avbrytelser i samme retning i form av mere finkornede typer over på fastlandet, bl. a. i den nevnte høide Vardåsen. Innenfor grensen er den velkjente grovkornede Fevik-granitt-type helt fremherskende. 2 eller 3 steder er iaktatt innesluttete gneispartier av nogen 10-meters utstrekning. En større rolle spiller 2 eller 3 mørke middels- til finkornede bergartstyper som hører genetisk sammen med hovedgranitten og er eldre enn denne. Disse typer finnes stort sett i lavtliggende partier og er ofte omgitt av oprakende berg av hovedgranitten. De danner således en stripe langs kysten fra et sted nord for Hesnesøya til øst for Ranvikfjorden („Storesand“). Fra Moisanden strekker sig et parti over mot Vikkilen og videre over denne til Gimle. Fra Ranvikfjorden kommer man i nordvestlig retning til en rekke småpartier, det innerste rett nord for Temsevatn. Blandt disse mørke typer kan man utskille en eldre grå og en yngre rødlig; som den yngste kommer så hovedtypen. I rekken eldst—yngst viser det sig her at mikroklinpertitt tiltar i mengde, likeså kvarts, mens plagioklas, biotitt, hornblende, titanitt, erts og apatitt avtar. Samtidig avtar plagioklasens anortittgehalt. Vi har altså en differensiasjonsrekke fra basisk til sur. Hornblende optrer for øvrig bare i de eldste (grå) typer, og her i sterkt varierende mengde. De hornblenderikeste typer er påfallende fattige på titanitt, og den titanitt som optrer er tydelige rester av større individer. Man har her inntrykk av en metamorfose hvorunder hornblende er dannet og titanitt opspist. Hvor det i så fall er blitt av det opbrukte titan er ennå ikke undersøkt. Yngre enn hovedtypen er en mengde aplittganger som optrer både innenfor og utenfor grensen. Likeså pegmatittganger, som er små og få. En større pegmatittgang finnes innenfor grensen nord for Holletjern, en utenfor grensen på høiden mellom Grimstad kirke og Vikkilen; begge disse har vært drevet. I den siste har jeg funnet litt euxenitt, men en aldersbestemmelse ved hjelp av radioaktive mineraler synes utelukket. De yngste bergarter i området er den store rombeoporfyrgang, som gjennomsetter hovedtypen på toppen av Fjæreheia; den er på dette sted ca. 30 m bred og inneholder store bruddstykker av granitten; for øvrig krysser den hele området omtrent parallelt med strøket. Videre en liten diabasgang som gjennomsetter hovedtypen på Hesnesøya. Den har et knekket forløp, og de to retninger som herved antydes synes å svare til hovedsprekkesystemene i området. — Det blev nevnt at de mørke typer innen granittområdet finnes i lavtliggende partier. Dette har sikkert delvis sin grunn i at de denuderes lettere enn hovedtypen. Men flere steder kan man også se at småflekker av hovedtypen ligger oppå de mørke, slik at hovedgranitten delvis må være intrudert over de eldre typer. — Også hovedtypen er sikkert sterkt neddenudert. At vi befinner oss i et dypt nivå synes å

fremgå meget tydelig av den totale mangel på grensefacies hos hovedgranitten og av den sterke migmatittdannelse utenfor grensene. De omgivende bergarter må ha holdt sig omtrent på granittens størknings-temperatur i meget lang tid.

Efter I. Oftedals foredrag fremkom uttalelser av T. Barth, S. Føyn, H. Rosendahl og foredragsholderen.

EKSKURSJON SØNDAG 30. MAI 1937

31 deltakere fra Norsk geologisk forening og Geologisk amatørklubb. Ledere professor O. Holtedahl og assistentgeolog S. Føyn.

Man studerte Alnsjøfeltet med dets store rikdom på bergartstyper av vulkansk og sedimentær opprinnelse. Turen gikk fra Burulla ved Grorud til Alnsjøen og videre over Storhaug ned til Østre skytterlag. Veiledende foredrag blev holdt av de to ledere, dessuten gav statsgeolog S. Foslie en utredning om kisleforekomster i Oslotrakten.

MØTE TORSDAG 11. NOVEMBER 1937

Tilstede 27 medlemmer og 16 gjester.

Formannen leste op en meddelelse fra Geografiska sällskapet i Finland om at det den 22de januar 1938 feirer sin 50-årsdag. Representanter for Norsk geologisk forening innbydes til å delta i denne fest.

Innvalg av nye medlemmer:

1. Herr SVEN ERIK LUNDBY, Brumunddal.
Foreslått av H. Rosendahl og H. Bjørlykke.
2. Cand. mag. AAGE KJELLERØD, Postboks 180, Lysaker.
Foreslått av S. Føyn og G. Holmsen.
3. Docent HARRY VON ECKERMANN, Skepparegatan 66, Stockholm.
Foreslått av Th. Vogt og Tom. Barth.
4. Statsgeolog N. MAGNUSSON, Sveriges geol. undersökning, Stockholm 50.
Foreslått av Th. Vogt og Tom. Barth.
5. Statsgeolog ALVAR HÖGBOM, Sveriges geol. undersökning, Stockholm 50.
Foreslått av Th. Vogt og Tom. Barth.
6. Professor J. D. H. DONNAY, Geological Department, Johns Hopkins University, Baltimore, Md., U. S. A.
Foreslått av I. Oftedal og Tom. Barth.

TH. VOGT: *Betraktninger over kisleforekomstenes dannelse*. Trykt under titelen „Origin of the injected pyrite deposits“. Norges tekniske høiskoles avhandlinger til 25-årsjubileet 1935, p. 595—609. — Norske vi.-selsk. skr. Trondheim 1935 I, nr. 20.

Efter foredraget uttalte sig C. W. Carstens, Th. Vogt, S. Foslie.

C. W. CARSTENS uttalte, at en del kisforekomster antakelig nødvendigvis av alle geologer må fortolkes som hydrothermal-metasomatiske, således 1) de typer, som optrer i kalkstens- og marmorbergarter og 2) de typer, som optrer i umiddelbar kontakt med trondheimittiske, eventuelt granittiske bergarter. Men mellom disse 2 typer av kisforekomster og de av Vogt som „magmatiske“ opfattede typer (de typer, som vel fortrinsvis er knyttet til gabbrobergarter) finnes der i en rekke tilfelle hverken strukturelle, mineralogiske eller vesentlig kjemiske avvikelser. De „magmatiske“ (eller „gabbroidale“) kisforekomster viser på en flerhet av steder en utpreget båndet tekstur og tildels meget høi ZnS-gehalt (overgangsled til typiske zinkforekomster) og leilighetsvis relativ høi CaCO_3 -gehalt. Og enn videre viser disse forekomster meget almindelig metasomatiske omvandlingstrin av de forskjellige ertsmineraler samt en sidesten, som vel i alle tilfelle er sterkt kloritisert eller sericitisert (s: mineraler, som tyder på utpregede lavtemperaturdannelser). Den slutning ligger derfor nær at samtlige kisforekomster er av hydrothermal-metasomatisk opprinnelse.

Taleren berørte dernest den utenlandske literatur på området fra de siste årtier og nevnte herunder at på basis av en rekke detaljundersøkelser i forskjellige verdensdeler er nu en meget vesentlig del av svenske, tyske, engelske og japanske forskere gått over til den opfatning, at fjellkjedenes kisforekomster er av hydrothermal-metasomatisk karakter. Flere forskere med tyskeren F. Behrend i spissen hevder endog, at svovlkis ikke er stabil i magmatisk tilstand. Taleren nevnte i tilslutning hertil en del eksempler på utenlandske hydrothermal-metasomatiske kisforekomster, således fra Spania og U. S. A.

For å kunne forklare forskjellen i dannelse mellom nikkelmagnetkisforekomstene på den ene side og fjellkjedenes kisforekomster på den annen har VOGT satt op 2 diagrammer med et „tørt“ resp. „vått“ gabbromagma. Ifølge disse diagrammer „trekker“ kismineralene i den førstnevnte type malmforekomster — på grunn av tidlig utsondring — Ni-gehalten ut av magmaet, mens kismineralene i den sistnevnte type — på grunn av en senere krystallisasjon — overlater magmaets Ni-gehalt til silikatmineralene. Etter Vogt er således kisforekomstenes gabbrobergarter NiO-rikere enn nikkelmagnetkisforekomstenes gabbrobergarter (noriter). Men dette forhold er ikke verifisert — det motsatte synes snarere å være tilfellet, hvorved grunnvollen for hele den teoretiske utvikling ryker overende.

Vogts forklaring av Feøy-forekomstens dannelse synes svært kunstig og er neppe riktig. Feøy har nikkelmagnetkisforekomstenes mineralskap og kjemiske sammensetning men kisforekomstenes form og karakter. Taleren mente, at det lå nærmere å fortolke Feøy som en metamorfosert nikkelmagnetkisforekomst.

STEINAR FOSLIE: Det anføres ofte at våre kisforekomster i løpet av desennier har vært studert så overordentlig grundig; men ikke over en eneste av dem foreligger der ennu publisert nogen monografi på samlet geologisk-mineralogisk-geokjemisk grunnlag.

Der blir derfor lett en tendens hos den enkelte geolog, ved genetiske betraktninger å legge hovedvekt på de enkeltforekomster eller grupper av forekomster, som han selv har best kjennskap til. Helst skulde man vente med disse genetiske diskusjoner til der forelå mere av fullt bearbeidet materiale enn idag.

Tilhengerne av de liquid-magmatiske teorier har allerede for lenge siden vært på det rene med, at der måtte anbringes adskillig vann i disse kismagmaer for i det hele å forklare dem, og der har siden vært en påtakelig tendens til å anbringe mer og mer vann i dem ved stadig lavere temperatur, så man sterkt nærmer sig de fysikalske forhold hvorunder de vanlige hydro-metasomatiske prosesser foregår. Imidlertid er der et prinsipielt skille mellom de to prosesser, som der ikke kan bygges nogen bro over.

Uten ved denne anledning å ville komme inn på spørsmålet i sin almindelighet, vil jeg bare si, at for den største gruppe av norske kisforekomster kan jeg ikke uten videre slutte mig til professor Vogts synsmåter. Det gjelder de forekomster som optrer i „grønstensformasjonen“ (de ordoviciske lavaer), representert ved Grong, Løkken og flere andre. Jeg har tidligere i diskusjoner hevdet, at disse ikke lenger som hittil bør henføres til den såkalte Røros—Sulitjelma-gruppe. Så vel i sin geologiske optreden, som først og fremst i sin struktur, og tildels mineralogisk (ubetydelig magnetkis, konstant jernfattig zinkblende) er de så vidt særpregede, at jeg vil foreslå dem utskilt som en Grong-Løkken-gruppe.

For Grongforekomstene er der flere omstendigheter som avgjort taler imot en liquid-magmatisk tydning. For det første er der ingen nær tilknytning til intrusiver av nogen art, for det annet er der innen en og samme forekomst overordentlig omfattende variasjon for innholdet ikke alene av svovl, men også av kobber, zink og karbonater. Variasjonene kan være forholdsvis uavhengig av hinannen og står ikke i noget som helst symmetrisk forhold til malmens begrensning.

For andre grupper av forekomster kan en direkte metasomatisk tydning også by på vanskeligheter. En forekomst som Bjørkåsen f. eks. består av en grovkornig blanding av omtrent like deler kvarts og svovlkis, og disse to fysikalsk og kjemisk meget forskjellige mineraler optrer i et påfallende konstant mengdeforhold fra heng til ligg og fra den ene ende av feltet til den annen.

Nu er der imidlertid en faktor som det har vært tatt forbausende lite hensyn til ved bedømmelsen av disse spørsmål hos oss. Jeg omtalte den allerede på bergmannstinget ifjor (høsten 1936) og vil gjerne gjenta det her.

I fjellkjede-formasjonene hvor alle våre kisforekomster optrer, er som bekjent ikke alene sedimentene, men også de magmatiske bergarter som har interesse i denne forbindelse, alltid mer eller mindre metamorfe, omkrystallisert i forskjellige facies. Det skulde da ligge nær å tro at dette også i mange tilfelle kan ha influert på kisforekomstene selv.

Efter mitt kjennskap til disse viser det sig helt påfallende, at de forekomster som optrer i bergarter av grønstensfacies (epizonen) som

regel er karakterisert ved meget finkornig struktur og meget intim blanding av de inngående mineraler. Dette er tilfelle med Grong, Løkken, Stord m. fl. Overordentlig påfallende er det at vi finner det samme forhold i de sydspanske kislefelter, som optrer innen enda mindre metamorfe bergarter.

Kommer vi derimot over i høimetamorfe strøk, som i store deler av Nordland (ren amfibolitfacies), finner vi overalt distinkt grovkrystalline kiser. I praksis viser forskjellen sig meget markert derved, at disse lett lar sig mekanisk anrike og separere, hvad der oftest er vanskelig eller umulig for de andre.

I mange tilfelle synes det videre som det er de relativt grovkornige kiser som er mest ensartede gjennom hele massen, ganske som man skulde vente det hvis der har foregått en homogenisering i forbindelse med omkrystallisasjon.

Disse iakttagelser er her bare nevnt helt summarisk, fordi de er så påfallende og så viktige. Forholdet krever et videre regionalt studium. Det er imidlertid klart at det har betydelige konsekvenser også for den genetiske tydning.

THOROLF VOGT: I anledning av dr. Carstens' innlegg vilde foredragsholderen uttale følgende. De synspunkter han var kommet til, og som var fremlagt her i aften, var en logisk videre utvikling av de synspunkter som han hadde fremlagt i sitt foredrag i 1921 i Stockholm: Bidrag til Sulitelmakisenens geologi, Geol. fören. förhandl. B. 43, s. 480—488. Her hadde han tydet sericitiskifrene ved kisforekomstene som metasomatisk omdannede skifre, og antatt at kismagmaene hadde vært ladet med gasser, særlig vann. Han trodde ikke det var noe av betydning i foredraget fra 1921 som han ikke vedkjente sig idag, og han kunde derfor ikke medgi at han befant sig på noe tilbaketog, som hevdet av Carstens under henvisning til Ramdohr. Selv om Ramdohr ikke kjente dette arbeide, som var foredragsholderens eneste teoretiske innlegg i spørsmålet om kisforekomstenes dannelse inntil 1935, burde Carstens kjenne det.

Foredragsholderen hadde forlenget vært på det rene med at en rekke kisforekomster var av metasomatisk karakter, og mente også at dette var kommet klart frem i hans foredrag. Forskjellen mellem Carstens' og hans opfatning var den, at mens Carstens antar at alle kisforekomster er metasomatiske, så antar foredragsholderen at man har så vel metasomatiske som likvid-magmatiske forekomster. Han mente at dette gikk klart frem av hans foredrag. Det kan for øvrig også henvises til det allerede trykte arbeide. Når Carstens henviser til Behrends og andres antakelse, at svovlkis ikke er stabil i magmatisk tilstand, så måtte dette medføre som en logisk konsekvens, at heller ikke typiske nikkelmagnetkisforekomster, som ofte fører svovlkis, kunde være likvidmagmatiske. I sin opfatning om kisforekomstene følger Carstens åpenbart helt ut den metasomatiske skole, som har bragt så meget utmerket nytt, men som efter foredragsholderens mening var gått for langt på flere punkter, således når det gjelder en del av kisforekomstene og en del av pegmatittgangene.

Når det gjaldt nikkelinnholdet i de forskjellige malmer mente foredragsholderen at det var logisk uundgåelig å trekke de slutninger han hadde gjort. At anrikningen av nikkel i nikkelmagnetkisforekomstenes sulfider måtte ha funnet sted på et meget tidlig trin, var en slutning man meget vanskelig kunde komme bort fra. Dette trekk er i virkeligheten et av de beste belegg for nikkelmagnetkisforekomstenes tidligmagmatiske karakter. Videre var det uimotsigelig at nikkelet følger magnesien i silikatene, og derfor går inn i disse på et meget tidlig trin under krystallisasjonen. Nettopp de to demonstrerte diagrammer var kjernepunktet i foredraget, og representerte meget vel begrunnede synspunkter. Med hensyn til Carstens' innvending må det først nevnes at sulfidmassen er overordentlig liten i forhold til silikatmassen i gabbroene, og selv om Ni anrikes flere hundre ganger i sulfidene i forhold til i silikatene, tør det være sannsynlig at nikkelinnholdet i silikatmassen (gabbroen) neppe blir merkbart forrykket. Dernest vilde han peke på at svovel ikke er bestemt i de bergarter med nikkelgehalter som foreligger fra J. H. L. Vogt, og at de verdier man får for silikatenes nikkelinnhold derfor blir absolutte maksimalverdier. Sannsynligvis vil nikkelinnholdet i selve silikatene være mindre enn analysene gir uttrykk for, siden der sannsynligvis er tilstede litt sulfider med relativt høit Ni-innhold. Dernest vilde han bemerke, at det heller ikke av Carstens var henvist til noe empirisk materiale, som kunde begrunne hans standpunkt for ikke å kunne akseptere foredragsholderens teori.

Med hensyn til dannelsen av Fegø nikkelførende sulfidforekomst, mente han det var oplagt at Carstens' tydning av denne som en metamorf normal nikkelmagnetkisforekomst ikke strakk til. Forekomstens form, dens beliggenhet i forhold til gabbrobergartene, dens rike kvartsinnhold o. s. v. er forhold som ikke kan forklares bare ut fra en metamorfose av en normal nikkelmagnetkisforekomst etter dannelsen.

I anledning av Steinar Foslies interessante innlegg vilde han gjerne henvise til, at han hadde fremhevet ganske sterkt i sitt foredrag at man ikke kunde anta en ensartet opprinnelse for alle kisforekomster. Den finkornete Løkken—Grongtype som finnes i områder med effusiv grønsten, representerer uten tvil en særegen forekomsttype, med særegne problemer. Han vilde imidlertid nevne at han inntil videre anså Løkkenkisen (hovedkisen) for magmatisk, og at han her bl. a. bygget på iakttagelse angående forholdet mellom kisen og magnetittpartier i hengen av kisen. Han hadde medbragt en blokk, som han hadde fått planslepet, og som viste hvad man måtte betegne som en eruptiv breksie, med eldre magnetittbruddstykker brutt op av en yngre kismagma.

THOROLF VOGT: *Leptittformasjonens jernforekomster i Norge.*

I løpet av somrene 1935—1937 hadde foredragsholderen benyttet en kort tid hver sommer til å besøke en rekke jernmalmsforekomster i Sør-Norge, som kunde antas å være av interesse når det gjaldt spørsmålet om leptittformasjonens optreden her. De forekomster det gjelder er særlig Arendalfeltets skarnforekomster og Søftestad apatittrike jernforekomst i

Nissedal, Telemark. For begge disse forekomst-typers vedkommende har det vært fremhevet i eldre tid, i 1890-årene og delvis før, særlig av J. H. L. Vogt, at det eksisterer stor likhet med mellemssvenske jernforekomster, med henholdsvis skarnforekomster av Persbergtypen og apatittjernforekomster av Kirunatypen (Grängesberg). Ved foredragsholderens undersøkelser var det blitt bekreftet at det eksisterte en rekke likhetspunkter her. I de store og verdifulle monografier som nå foreligger over de svenske forekomster har spesielt Nils Magnusson for skarnforekomstenes vedkommende og Per Geijer for Kiruna-typens vedkommende hevdet en nær tilknytning av malmene til leptittformasjonen. Derved får malmforekomster av disse typer til en viss grad også stratigrafisk betydning.

Med hensyn på Arendalsfeltets skarnforekomster blev der først pekt på den forholdsvis høie mangangehalt, som efter foredragsholderen er å anse som et fundamentalt genetisk trekk. Relativt Mn-fattige forekomster, som Bråstad, Torbjørnsbu og Langsev, fører en malm med omkring 0.4—0.8 % Mn. Middels manganrike malmer, som Klodebergmalmen, fører omkring 1.4.—2.1, i gjennomsnitt ca. 1.7 % Mn, og relativt manganrike malmer, som Voksnesmalmen, fører ca. 4.4 % Mn. Jerngehalten i disse malmer ligger omkring 35—60 % Fe. En mangananrikning av denne art tør antas å ha funnet sted under tilgang på surstoff i nærheten av eller i overflaten, således som antatt for de mellemssvenske forekomster av J. H. L. Vogt, Hj. Sjögren og N. Magnusson. Her er dog som kjent adskillelsen av jern og mangan tildels gått langt videre, men på den annen side har man også en rekke malmer med tilsvarende mangangehalter. Malmens innhold av fosfor (0.025—0.055 % P), svovl (0.01—0.04 % S) og titan (helt ubetydlig), ligger omtrent som for typiske mellemssvenske skarnmalmer.

Arendalsfeltets skarnmalmer kan efter hvad foredragsholderen hittil har sett inndeles i følgende typer, efter de i malmen optredende silikatmineraller:

1. Granat og monoklin pyroxen, tildels litt spinell. Torbjørnsbutypen. Svarer nærmest til Harald Johanssons Persbergtype.
2. Monoklin pyroxen, tildels med noe kalkspatt, skapolitt og spinell. Klodeborg-typen.
3. Monoklin-pyroxen og hornblende, til dels med noe kalkspatt, epidot og skapolitt. Bråstad—Lærestveit-typene. Svarer nærmest til Harald Johanssons Bjørnbergtype.
4. Kalkspatt med endel biotitt og kloritt. Malm fra Solberg ved Arendal. Ligner malm fra Skärstöten.
5. Serpentin. Malm fra Bråstad. Svarer nærmest til Harald Johanssons Bergsäng—Gubbo-type.

De omgivende skarn består i meget stor utstrekning av granat og monoklin pyroxen. Analyser av disse og andre mineraler er nylig satt i gang, og vil foreligge senere. Videre forekommer strålsten, lokalt meget grønn hornblende, samt kalkspatt, epidot (med kalkspatt), rhodonitt (i hvert fall delvis på yngre årer), skapolitt o. s. v. Noen magnesiametasomatose med dannelse av antofyllitt eller cordieritt er ikke iaktatt, men det ser

ut til at i hvert fall en del av hornblenden er yngre enn granat-pyroxen-skarnet. Epidoten synes også å være yngre enn dette. Kalkspattårer dels med skapolitt og dels med oligoklas setter videre igjennom det eldre skarn. Sulfidene i malmen og i skarnet er åpenbart i flere tilfelle dannet etter maldannelsens første periode, som ved de mellemsvenske forekomster. Helt sene dannelser er datolitt og prehnitt, samt også babingtonitten, som oprinnelig blev beskrevet fra Arendal, og som nylig også er funnet ved de mellemsvenske skarnforekomster. Babingtonitten er for øvrig dannet på et „anchizeolittisk“ stadium i tilknytning til yngre granittpegmatittganger som gjennomsetter skarn og malm. Mineralet er av helt samme genetiske type som den nylig av Richmond beskrevne babingtonittforekomst ved Blueberry Mts.

Foredragsholderen oppfattet i hovedsaken den primære jernmangan-konentrasjon som helt eller meget nær suprakrustal, dannet som antatt av Magnusson for hovedmassen av de mellemsvenske skarnforekomster, enten direkte som sedimenter, eller som metasomatose i karbonatbergarter nær overflaten. Skarnet opfattes i hovedsaken som et reaksjonsskarn, men det er samtidig klart at forekomstene har hatt en lang utviklingshistorie, med antakelig flere stadier av mineraldannelse. Det tør være at Arendalsfeltets skarnforekomster for enkelte trekk vedkommende adskiller sig fra de mellemsvenske, men for fundamentale trekk vedkommende er der efter foredragsholderens mening meget stor likhet. Foredragsholderen vilde dog ikke utelukke at der også kunde finnes kontakt-metasomatiske jernforekomster i mindre utstrekning, på samme måte som i Mellem-Sverige. I den forbindelse kan det nevnes at vesuvian er påvist ved et par av Arendalsforekomstene, om enn som et sjeldent mineral.

Med hensyn til Søftestad apatittrike jernmalmforekomst er der særdeles store likheter med Kirunatypens forekomster i Sverige, og spesielt da med Grängesbergforekomstene. Ved Søftestad har man en jernmalm med ca. 1—3 % P, 0.005—0.03 % S og 0.02—0.09 % Mn, omtrent svarende til de fosforrike malmer av Kirunatypen i Sverige. Malm-mineralene er magnetitt og „primær“ jernglans, ofte med magnetittkorn i jernglansen, av samme type som ved Grängesberg. Apatitten er en fluorapatitt uten klor. Titanitt finnes som regel ikke, men kan opptre meget rikelig i apatittrike striper. Videre finnes i jernmalmen kvarts, albitt, lys grønn hornblende, samt en liten men meget karakteristisk mengde av ortitt. „Skarn“-striper i malmen består av kvarts, albitt, monoklin pyroxen, almindelig hornblende, leilighetsvis litt granat, epidot og flusspatt, samt apatitt og ortitt. Malmen synes å stå Risbergtypen ved Grängesberg nærmest.

Sidestenen består av relativt finkornige albittgneiser med biotitt og hornblende, med klare og skarpe grenser mot jernmalmen, som også har samme plateform som er så karakteristisk for mange forekomster av Kirunatypen. Foredragsholderen oppfattet malmen som en magmatisk injeksjon, med efterfølgende metasomatose i mindre utstrekning. Det ligger overordentlig nær å opfatte forekomsten i overensstemmelse med Per Geijers opfatning av de svenske forekomster av Kirunatypen: som magmatisk differentiasjonsprodukt av leptitt-vulkanismens egen magma.

En tredje malmtypen i Arendalsfeltet, nemlig Lyngrott-typen, tør være av mindre interesse i denne forbindelse, siden man så vidt vites ikke kjenner tilsvarende forekomster i Sverige. Siden denne type imidlertid synes å ha visse tilknytninger til Kirunatypen, som påpekt av Geijer, skal den i hvert fall nevnes. Man har her en apatittrik jernmalm i meget nær tilknytning til en granitt, delvis med sliredannelser i denne. Granitten er forholdsvis grovkornig, med kvarts, sur plagioklas, mikroklinpertitt, magnetitt, monoklin pyroxen, almindelig hornblende, zirkon, titanitt, apatitt og biotitt. Malmen er en magnetittmalm med kvarts, feltspatt, lys grønn hornblende, monoklin pyroxen og delvis meget rikelig med apatitt. Denne er imidlertid i det vesentlige en klorapatitt, med lite fluor.

En fjerde forekomst-type, nemlig de såkalte koboltfalbånd på Modum, blev nevnt som muligens analog med f. eks. Vena koboltforekomst i Mellem-Sverige. Det har vært henvist til denne analogi alt for omkring 100 år siden av Bøbert. Ellers finnes der i strøket Sørlandet—Modum en rekke yngre forekomst-typer, som blev omtalt i forbigående, men som var av mindre interesse i denne forbindelse.

Foredragsholderen omtalte videre de geologiske slutninger som han fant det naturlig å trekke ut fra det foreliggende materiale. I Norge har særlig Arne Bugge i den senere tid innlagt sig fortjeneste ved nærmere undersøkelse av de prekambiske kompleks i strøket Sørlandet til Modum. Her har han skilt ut Bamleformasjonen og Kongsbergformasjonen, idet han dog antar at disse formasjoner hverken inneholder sedimentære eller effusive ledd. De tidligere av Carl Bugge beskrevne andesitter etc. i Kongsbergformasjonen, oppfattes således av Arne Bugge som intrusive finkornige dioritter.

Den del av Bamleformasjonen som fører karbonatbergarter og skarnforekomster oppfattes av foredragsholderen som den undre del av leptittformasjonene. Foredragsholderen oppfattet de omkrystalliserte kalkstener f. eks. i Grimstadtrakten som ekte sedimenter, i likhet med Holte-dahl. Sterkt omvandlede natronleptitter turde skjule sig i den grå gneis. Foredragsholderen hadde også sett bergarter av samme type som sterkt omkrystalliserte kali-leptitter, men hadde hittil ikke kunnet overbevise sig om at det virkelig var effusiver man hadde for sig. Det han hadde sett turde muligens være finkornig røde urgranitter. Det var imidlertid av stor interesse at O. A. Broch hadde beskrevet leptitter eller leptittlignende bergarter, med magnesiometasomatose fra Nesodden ved Oslo, et felt som turde sees i sammenheng med den undre del av Bamleformasjonen. En fortsettelse av Brochs utmerkete undersøkelser mot syd og øst turde antas å gi interessante resultater.

Kongsbergsformasjonen og resten av Bamleformasjonen, med sine glimmerskifre, men uten karbonatbergarter, var det også naturlig å henføre til leptittformasjonen, men fortrinnsvis til den øvre del (den bottniske formasjon).

Begge disse formasjonsledd måtte imidlertid være meget sterkt metamorfosert og antakelig også omdannet ved palingenese, likesom de var intrudert med basiske og sure intrusiver i overordentlig stor utstrekning. En gruppe av granitter som stort sett var intrudert parallelt med skrifrighetsplanene av det eldre kompleks, lå det nær å oppfatte som værende samtidig

med de mellemsvenske urgranitter. I strøket Sørlandet—Modum hadde man videre en rekke forekomster av cordieritt og antofyllit-gedritt, som tydet på en utstrakt magnesiametasomatoze, antakelig i tilslutning til urgranittene. Tildels hadde man rene antofyllit-cordierittfelter av fullstendig samme karakter som i Mellem-Sverige og Syd-Finnland. Foruten disse granitter av urgranitt-typen har man også overskjærende granitt-massiver av „sencyklisk“ type. Det bemerkes at foredragsholderen benytter betegnelsene Bamleformasjonen og Kongsbergformasjonen bare om de her opptredende suprakrustale ledd, og altså forsåvidt med en annen begrensning enn anvendt av Arne Bugge.

De ovenfor omtalte slutninger stod i god overensstemmelse med de aldersbestemmelser av radioaktive mineraler som nylig har vært omtalt av Helge Backlund. Mens pegmatittmineraler fra området nord for Ladoga og ved Arendal (ca. 1110—1120 mill. år) peker på noenlunde samtidige granitter, antakelig svioniske sencykliske granitter) gir pegmatittmineraler fra Østfold (ca. 885—950 mill. år) en yngre alder for den gotiske Iddefjord—Bohuslen-granitt. Backlund antar derfor også en svekofennisk (svionisk) alder av Arendal—Sørlandsfeltet. Det kan for øvrig henvises til at både Sederholm og Alvar Högbom i 1931 har betegnet Sørlandsfeltet som hørende til leptittformasjonen.

Foredragsholderen vilde sammenfatte sine slutninger derhen, at man i Bamle—Kongsberg-formasjonene sannsynligvis hadde et meget sterkt omdannet grunnkompleks tilhørende leptitt-formasjonen. Om enn strøketretningen (NNO—NO) avvek noe fra Svekofennidenes hovedretning, turde det være naturlig å opfatte komplekset som hørende til den svioniske cyklus, efter Magnussons terminologi. Efter muntlig meddelelse av Magnusson er han stemt for å benytte betegnelsen svionisk-bottniske for denne prekambriske cyklus. Dette forhindrer dog ikke at Bamle-Kongsbergformasjonene muligens kan ha deltatt i eller vært påvirket av senere orogenier.

I det øieblikk man har fått et holdepunkt for en korrelasjon mellem Syd-Norge og Mellem-Sverige i Kongsbergs—Bamle-formasjonene og leptitt-formasjonen, ligger det overordentlig nær å søke korrelasjoner også for yngre suprakrustalkompleks i Syd-Norge. Her har man fremfor alt Telemarksformasjonen, som særlig er undersøkt i nyere tid av Werner Werenskjöld, Carl Bugge, miss D. Wyckoff og Arne Bugge. At Telemarksformasjonen, eller Telemarksformasjonene som man kanskje heller bør kalle dette kompleks, er yngre enn Kongsberg—Bamle-formasjonene, tør være almindelig antatt. Det fremgår også helt generelt av deres helt forskjellige grad av omdannelse i nærliggende områder. En sammenligning med det nordlige Mellemsvenske område ved Loos-Hamra, hvorfra Harry von Eckermann nylig har publisert en oversikt over sine viktige undersøkelser, synes å være særlig fruktbringende, bl. a. fordi man her har representert så vel eldre som yngre prekambriske suprakrustaler i merkelig fullstendig utvikling.

På grunnlag av Werenskiolds arbeide, med komplettering for den laveste dels vedkommende efter C. Bugge og for Gaustadfeltets vedkommende efter D. Wyckoff, kommer man til følgende aldersskjema:

8. Granitt i Tinn og Venåsfjell, yngst.
7. Basiske intrusiver.
6. Telemarksgranitt i S og NW.
5. Kvartsitt i Lifjell og Blefjell etc.
Diskordans (W. W.).
4. Øvre effusivserie (kvartsporfyrrer) i Heddal og Hovin etc.
3. Kvartsitt i Gausta og Svartdal etc.
Diskordans (W. W. og D. W.).
2. Undre effusivserie (eldst grønnsten, yngst kvartsporfyrrer) i Tuddal og Tinn etc.
Diskordans (C. B.).
1. Skiferformasjon med kvartsitter, eldst.

Her er det overordentlig naturlig å parallellisere den undre effusivserie i Telemark med effusivene i den undre Loos-serie, og videre med

*Forsøk til korrelasjon mellom Syd-Norges og Sveriges
eldre prekambriske formasjoner.*

Syd-Norge	Sverige		
Yngre graniter i Telemark, f. eks. Tinngranitten og Venås fjellets granitt	Sorselegranitt Linaganitt p. p. Rätanganitt		Karelsk cyklus
Kvartsitt i Blefjell etc. i Telemark	Øvre Noppi-serie: Kvartsitter og skifre	Vakko- forma- sjonen og Vargfors- forma- sjonen	
Øvre effusivserie i Telemark: kvartsporfyrrer	Undre Noppi-serie: Kvartsporfyrrer		
Kvartsitt i Gausta etc. i Telemark	Øvre Loos-serie		
Telemarksgranitt p. p.	Smålandsgranitt, Filipstadgranitt, Risberggranitt		Gotisk cyklus
Undre effusivserie i Telemark: Eldst grønnsten, yngst kvartsporfyrrer	Smålandsforfyrrer. Undre Loos-serie: eldst grønnsten, yngst kvartsporfyrrer		
Skifer og kvartsitter i Telemark	Sub-Loos-serie. Diverse kvartsitter og skifre i Mellem-Sverige		
?	Stockholmsgranitt Fellingsbrogranitt		Svionisk- bottnisk cyklus
Granittintrusjoner gjennomgående langs efter skifrihetsplan. Sørlandet—Modum etc.	Urgranitter		
Kongsbergformasjonen Bamleformasjonen	Leptitformasjonen		

Smålandsporfyrene. Telemarkseffusivene synes å være temmelig lik de nevnte svenske effusiver så vel petrografisk som m. h. t. metamorfosegrad. Der foreligger også spesielle likhetspunkter:

Således har man så vel i Telemark (efter C. Bugge) som i Loos-Hamra en undre grønnstensavdeling og en øvre avdeling bl. a. med kvartsporfyrrer. Videre synes bergartskompleksene under og over effusivene å være av stort sett samme karakter i begge områder.

I Sub-Loos-serien, under effusivene her, har man nedenfra regnet kvartsitt, skifer, kvartsitt, og øverst et konglomerat. Under Telemarkseffusivene har man efter C. Bugge en skiferformasjon med kvartsitter, og øverst et konglomerat.

I den øvre Loos-serie, over effusivene, har man en mektig serie som overveiende består av kvartsitter og sandstenkvartsitter, og som inneholder skifre, gråvakker, arkose og konglomerat. Over effusivene i Telemark har man en mektig avdeling med vel opbevarte kvartsitter, bl. a. med bølgeslagsmerker på lagflatene, samt også konglomerat. Både i øvre Loos-serie og i Telemark har man gamle brynestensbrudd, men hvor i Telemarksseriene våre brudd hører hjemme har jeg ikke fått bragt på det rene.

De ovenfor anførte forsøksvise korrelasjoner, med de derav følgende parallelliseringer, innen Sverige efter Magnusson og von Eckermann, er anført på tabellen på side 222. Her er, som det vil sees, de veldige områder av Telemarksgranitt (eller Telemarksgranitt pro parte) naturlig sammenført med Risberggranitten i Loos-Hamra samt med de veldige områder av Filipstadgranitt og Smålandsgranitt. Efter von Eckermanns og Magnussons korrelasjon blir derved den øvre avdeling av Telemarksformasjonene yngre enn de ekte Telemarksgranitter, noe som for så vidt ikke bygger på iakttagelser i Norge, men som må sees som en logisk følge av den foreliggende korrelasjon. Dette punkt tør være det svakeste ved korrelasjonen. På den annen side tør det være mulig eller sannsynlig at der blant det som kollektivt har vært betegnet som „Telemarksgranitt“ skjuler sig granitter tilhørende forskjellige aldre. De helt upressete, relativt unge granitter innenfor Telemarksformasjonenes område er det naturlig i hvert fall delvis, å sammenføre med von Eckermanns Rätanggranitt, Alvar Høgboms Sorselegranitt og Per Geijers Linagranitt pro parte.

De forholdsvis faste punkter i det ovenfor omtalte korrelasjonsforsøk anser jeg å være korrelasjonen av Kongsberg- og Bamle-formasjonene med Leptittformasjonen, og korrelasjonen av de effusive avdelinger i Telemark med de tilsvarende i Mellem-Sverige.

Efter foredraget uttalte sig S. Foslie, Th. Vogt, og C. Bugge.

THE PENTAMERACEA OF THE OSLO REGION

BEING

A DESCRIPTION OF THE KIÆR COLLECTION
OF PENTAMERIDS

BY

J. K. S. St. JOSEPH

WITH 23 FIGURES IN THE TEXT AND 8 PLATES

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Explanation of plates I—VIII

Preface.

The greater part of the material described in the present study was collected by the late Professor J. Kiær at the time of his detailed investigation of the Silurian rocks of South-eastern Norway. Kiær's stratigraphical results were published in his well-known monograph "Das Obersilur im Kristianiagebiete", and he had intended, apparently, to devote a separate work to a description of the fauna, especially the *Brachiopoda*. This projected work was unfortunately never completed, but Professor Kiær's entire collection, numbering several thousand specimens, is preserved at the Palaeontologisk Museum, Oslo. Of the *Brachiopoda*, the Pentamerids form the most widespread and important group, abundantly represented as they are in nearly all the different areas of the Norwegian Silurian. It appears that Professor Kiær had a few plates prepared, illustrating some of these Pentamerids, in view of a projected monograph on the *Brachiopoda* of Southern Norway: although many of the specimens had been identified, no notes exist, nor has it always been possible to determine the originals of Kiær's figures.

The Pentamerids are very abundant at many horizons in the Norwegian Silurian, but comparatively few genera and species are represented. All the material, however, is extremely well preserved, and instead of a state of preservation as casts, familiar in British specimens, not only do the interiors remain intact, embedded in matrix, but in many cases comparatively little exfoliation of the exterior shell has taken place. One further consideration enhances the special value of this collection. Nearly all the material has been very carefully labelled, so that the majority of specimens can be assigned to their original localities and horizons; with regard to the latter not only to a definite zone but often (by reference to the figures and tables in Kiær's monograph) to within a few feet in the succession.

With one or two exceptions the Pentamerids in question are not of great use for very detailed, stratigraphical zoning, and consequently a strictly palaeontological approach is adopted. By this means it is hoped the better to illustrate the facts that have been learnt concerning the evolution and origins of this group, and where necessary the work has been extended beyond the limits of this collection. Thus, with regard to the origin of the Pentamerids, specimens of

some of the early forms that occur in America and in Greenland have been examined, although without throwing much light on this problem. Again, the possibility that the essentials of the Pentamerid structures might be derived from such a form as the common Ordovician genus *Porambonites* led to an investigation of that genus. Representative specimens of each species and genus have, whenever possible, been compared with the type material, while an intensive search has been undertaken amongst the early literature on the subject with the aim of settling controversial points of nomenclature that have arisen.

The work, of which the results are here described, has been undertaken in the course of the last two years at the Sedgwick Museum, Cambridge. The writer wishes to express his thanks to Professor Høltedahl and Dr. A. Heintz for entrusting him with the description of this collection; and to the latter and to Dr. Leif Størmer for affording him facilities at the Palaeontologisk Museum, Oslo, and for guiding him over some of the classical Norwegian localities. He wishes, also, particularly to thank Professor O. T. Jones and Dr. O. M. B. Bulman for advice and kindly criticism, and Miss H. M. Muir-Wood and Mr. A. G. Brighton for access respectively to specimens in the British Museum (Natural History), London, and the Sedgwick Museum, Cambridge. Finally, he would express his thanks to the Department of Scientific and Industrial Research, London; to the Goldsmiths' Company, London, and to the Master and Fellows of Selwyn College, Cambridge, for the award of grants during the tenure of which this paper has been written.

Introduction.

The district of south-eastern Norway has long been recognized as a classic area for the study of the Silurian rocks, partly because of the continuous succession and the excellence of the exposures, and in part because of the abundance of the fauna, which is very largely of the shelly facies. This area early received the attention of geologists, but no detailed treatment appeared until comparatively recently. The original division of the Norwegian Lower Palaeozoic into nine groups was proposed by Kjerulf (1857 and 1865), and elaborated by later writers, but the first extensive treatment of the Silurian was due to Brøgger (1886 and subsequent papers) and Kiær,

who after two preliminary studies in 1897 and 1902, published his monograph "Das Obersilur im Kristianiagebiete" in 1908, and it is on this work that all subsequent advances must be based. His treatment was stratigraphical, and for the purposes of description he divided into seven districts the areas of occurrence of Silurian rocks, all of which lie within the down-faulted "Oslo region" extending from the mouth of the Oslo fjord northwards to Mjøsen. Since the faunas preserve a certain individuality as between district and district this division will be the subject of frequent reference in the present paper, and for convenience, the main characters of the successions in the different districts are summarized in Table I (p. 256). In the northern development the shelly fauna is scarcely represented, and it is mainly with the faunas of areas I, II, III and V that the present work is concerned.

The Pentamerids are characteristically fossils of the shelly facies, and to judge from a quantitative distribution — if this may serve as a general guide — their most favourable habitat was in fairly clear water of quite moderate depth. Thus, it may be observed that it is in the relatively clear-water deposits of 6 c from Malmøy, Asker and Holmestrand that *Stricklandia lens* is represented most abundantly, while the distribution of the typical form of *Stricklandia lirata* shows a definite preference for clear-water formations. *Pentamerus borealis* is most abundant in this region (at Ringerike and Hadeland), as elsewhere, in shallow-water limestones, while *Pentamerus laevis* [= *P. oblongus*] is commonest in the most calcareous development of 7 b at Malmøy, Ringerike and Holmestrand. These considerations do not appear to apply with quite the same force to *Clorinda*.

In addition to the specimens in the Kiær Collection the writer has examined much duplicate material in the Palaeontologisk Museum, Oslo, and the Sedgwick Museum, Cambridge, as well as material in the Riksmuseum, Stockholm and the Palaeontological Institut at Kåbo, Uppsala. In all, several thousand specimens of *Pentamerus* and *Stricklandia* have been available for study. A comparison with British material has been made in order to correlate the Norwegian succession with the rocks in the type areas in Britain. Though this can only be done on a broad scale, the results of such a comparison appear to demonstrate the probable absence of true Lower Llandovery, at least in part, in Norway. Further anticipation would be premature, and these points are discussed more fully in a later section.

Of the genera that are present in the collection, *Pentamerus* is represented by three species, *Stricklandia* by two species, *Clorinda* by three species, *Conchidium* by one species and the interesting genus *Holorhynchus* by the only species that is yet known. After a detailed study it has been found necessary to propose only two new species, but within the limits imposed by the extent of the material it has been possible to arrange specimens in morphological series, which serve to illustrate in more than one case possible lines of evolution.

In the Kiær Collection the matrix in which the specimens are embedded, usually consists either of fine-grained calcareous sediment, or of a mosaic of calcite crystals formed subsequently to the fossilization of the specimen. In either case, the infilling is not very susceptible to removal by a dental drill, and such a method of preparation does not yield very satisfactory results. To meet the necessary requirements — the obtaining of accurate and detailed information concerning the internal structure — the technique of serial-sectioning has been adopted with the preservation of closely-spaced transfers, followed by the construction of enlarged scale-models. Brief references to this method have already been published (St. Joseph, 1935 a, p. 317), and it remains to be observed that the method is an exact one, in that a record of each cross-section can be retained as a transfer, the latter being even better than a photographic print as the growth-lines of the shell are preserved. The transfer method is suitable for any hard matrix, and the only circumstance under which it does not give satisfactory results is when recrystallization of matrix and skeleton together has taken place. For the specimens in this Collection which are of relatively large size, transfer series spaced at 0.1 or 0.15 mm intervals have mostly been used, though there is now no mechanical difficulty in obtaining serial sections of solid specimens at least down to 20 μ .¹

Scale-models in beeswax of all the species, usually two of each species, have been constructed at magnifications between $\times 7$ and $\times 15$, in different cases. Many of these are illustrated in the plates, though figures can never demonstrate with the same conviction as

¹ For small specimens the grinding apparatus described and illustrated by Bulman ("British Dendroid Graptolites", *Palaeontogr. Soc. Lond. [Monogr.]*, pt. 1, 1927, pp. 4–5), has been found very useful. This yields sections which may be drawn with a *camera lucida* attachment to a microscope.

the models themselves, the three-dimensional relations between the internal structures. Serial transfers have been taken from several individuals of each species, and in the case of the commoner specimens such as *Stricklandia* or *Pentamerus* these have been supplemented by thin-sections. In this way, the interiors of at least 12 examples of each of the more abundantly represented species have been examined, by one method or another; nor does this number include the specimens (which are quite numerous) that have fractured along the median plane, to expose part of the internal structures. It is to be understood with regard to this number of individuals that the expressions 'rare' or 'common' etc, are used in the sequel, when discussing internal variation.

The nomenclature adopted in this paper includes many technical terms that are already very familiar in the literature of the subject, and it is thought that reference to text-figures will leave no doubt as to their usage. Different systems of nomenclature, indeed, exist, and reference may be made to the list of terms given by Schuchert and Cooper (1932, pp. 6—11, 162—5), to quote a recent treatment. It seems unlikely that so detailed a terminology as that applied, for example, to Mesozoic Telotremata, may ever be necessary for the Pentamerids. It is, in fact, this very simplicity of structure that enhances their value, in that they provide a clear opportunity in which to study under simple conditions in a closely related group, the effect of processes of change over a considerable interval of time.

The specimens are illustrated by plates and drawings of serial transfers. Of the latter, considerations of space have necessitated that only each alternate, or every third transfer be figured. It is thought that these are sufficient to illustrate adequately the changes occurring through the series. The drawings are numbered to correspond with the serial numbers on the transfers. In these drawings the upper of the two valves is always the ventral; ['ventral' and 'dorsal' are used to describe the two valves in preference to 'pedicle' and 'brachial', with which terms they are synonymous]. 'Left' and 'right' in the text, and in the descriptions of figures, are to be understood as referring to the left and right of the animal, thus when the specimen is viewed from the dorsal side with the posterior end uppermost, the left of the specimen is on the observer's right, and *vice versa*. Usage is far from uniform in this matter with different authors.

All the models and serial transfers prepared in connection with this work have been deposited in the Sedgwick Museum, Cambridge (hereafter referred to as S. M. C.), while the collection of specimens remains in the Palaeontologisk Museum, Oslo (hereafter referred to as P. M. O.). Duplicates of two of the models, S. M. C., A. 13504, and A. 13518 have been deposited in the P. M. O.

Morphology.

The Delthyrium and Pseudodeltidium.

The nature of the pedicle-opening at present forms the basis of the commonly accepted division of the Phylum Brachiopoda into four Orders, and it is thus unfortunate that there has been considerable laxity in the use of terms describing this portion of the shell. In the present connection, it is the characters of the Protremata and Telotremata that are in question, and the nomenclature used applies particularly to these two Orders. It may be suggested that descriptive terms should be employed as far as possible in the sense in which they were used by their proposers, being modified only in so far as later work has tended to give a clearer conception of the structure or function of the feature in question. The morphology of the pedicle-opening (= foramen, in the Articulata) has been discussed recently by Thomson (1927, pp. 63—79), and the nomenclature there adopted is partly followed in the present account.

When the ventral cardinal-area is divided medianly by a triangular fissure, the latter is usually termed a 'delthyrium' (Hall and Clarke, 1892, pt. i, p. 189 footnote). The delthyrium extends from the hinge-line towards the umbo, and it appears to serve, primarily at least, for the passage of the pedicle. The shape and size of the pedicle-opening may be modified in different ways by the secretion of shell-material united to the ventral valve, and it is in connection with the terminology of these modifications that confusion has arisen. One of the first writers to discuss the morphology of this part of the shell was von Buch, who proposed the term 'deltidium'¹ (1834 [1835], p. 35) for the covering that constricted the pedicle-opening in certain Brachiopods, and he figures as examples some species of *Terebratula s. l.* He considered as distinct arrangements the cases in which the deltidium

¹ "Dieses schließende kleine Schaalstück nenne ich das 'Deltidium'".

completely surrounded the foramen, bounded it only on its dorsal side, or was alternatively divided by the foramen into two entirely separate parts.

The term pseudodeltidium was first proposed by Bronn (1862, p. 242), who regarded it as distinct from von Buch's 'deltidium', defining it as follows:

"Wo jenes [Schnabel-]Loch gar nicht vorhanden, da bleibt die dreieckige und bis in die Buckel-Spitze reichende Deltidial-Öffnung entweder ganz unverschlossen, oder sie schließt sich durch ein ungetheiltes mit dem rechten und linken Rande fest verwachsenes flaches und in der Regel quer-gewölbtcs Pseudodeltidium, dessen Schloß-Rand gebogen ist und so, wie die ihm parallele Zuwachsstreifung des Deltidiums die Konvexität der Biegung nach hinten kehrt."

(Bronn 1862, pp. 241—2).

Bronn was evidently describing an undivided plate attached to the sides of the delthyrium and partly covering the delthyrial opening. He refers for examples to figures of *Thecidium*, *Spirifer s. l.* and *Chonetes* (Bronn, *op. cit.*, pls. 23 and 24, figs. A, B, D and N). Quenstedt (1868, p. 10) interpreted this to mean that pseudodeltidium was partly synonymous with deltidium, while Davidson appears to have used deltidium in a general sense for any constriction of the pedicle-opening consisting of one or two pieces or 'plates' (cf. Davidson, 1853, p. 61; 1884, p. 289).

The two separate plates present in many Telotremata, that cover the delthyrial opening to a greater or lesser extent, have been termed generically by many different authors (*e. g.*, Schuchert, 1897, p. 74), deltidial plates (= deltaria of Hall and Clarke, 1894), and when united they have been considered to form a 'deltarium' (of Hall and Clarke, 1894, p. 328), a 'pseudodeltidium' (of Schuchert, 1913, p. 359) or a 'symphytium' (of Buckman, 1918, p. 88). The term deltidium was taken by Beecher (1892, p. 142), Hall and Clarke (1892, p. 189; 1894, pp. 327—8), and Schuchert (1897, p. 74; 1913, p. 358) to include a superficially somewhat similar covering of the pedicle-opening in the Protremata, while pseudodeltidium was applied by Walcott (1912, p. 293) to a 'plate' which he considered to be the homologue in some Atremata and Neotremata, of the 'deltidium' of the Protremata.¹ In the same sense as this, Schuchert (1913, p. 358)

¹ This was Walcott's opinion, but it is very unlikely that the two structures are really homologous. Cf. *e. g.* Thomson, 1927, p. 66.

used the term homoeodeltidium. More recently, Thomson (1927, p. 68) and Schuchert and Cooper (1932, p. 7) restrict the term deltidium to a roughly triangular plate growing dorsally from the apex of the delthyrium in Protremata, and use the name deltidial plates for the structures which constrict the pedicle-opening in the Telotremata and which form a deltarium (of Hall and Clarke) or pseudodeltidium (of Schuchert) when united.

It will be seen from this that not only has there been little constancy in the usage of these terms, but that the meanings of 'deltidium' and 'pseudodeltidium' have come to be almost exactly interchanged. Deltidium first used by von Buch for a structure consisting of two plates covering the delthyrium of such forms as *Terebratula* and *Rhynchonella* s. l. now classed as Telotremata, has been used by recent authors for a single plate constricting the delthyrium in Protremata, while pseudodeltidium defined by Bronn as an undivided plate, has come to be used for the united condition of deltidial plates in Telotremata. Though it is likely, at least in certain genera, that the pseudodeltidium was secreted by a mantle-flap embracing the pedicle just as were deltidial plates, this is no reason for interchanging the meanings attached to these terms, while the only way to avoid further confusion is to use 'deltidium' and 'pseudodeltidium' in the sense in which they were employed by the proposers of these terms.¹ Pseudodeltidium, too, was used by Beecher as applying to the Protremata at the time that he proposed the four Brachiopod Orders at present in general use (1891, p. 355) and should be so employed for this reason as well.

The Pentameroidea are usually classed as Protremata, principally because of their close relationships with the Orthoidea: the presence

¹ 'Deltidium' of von Buch (1834) — in part, deltarium (of Hall and Clarke, 1894, and Schuchert and Cooper, 1932), pseudodeltidium (of Schuchert, 1913, *non* Bronn), and symphytium (of Buckman, 1918).

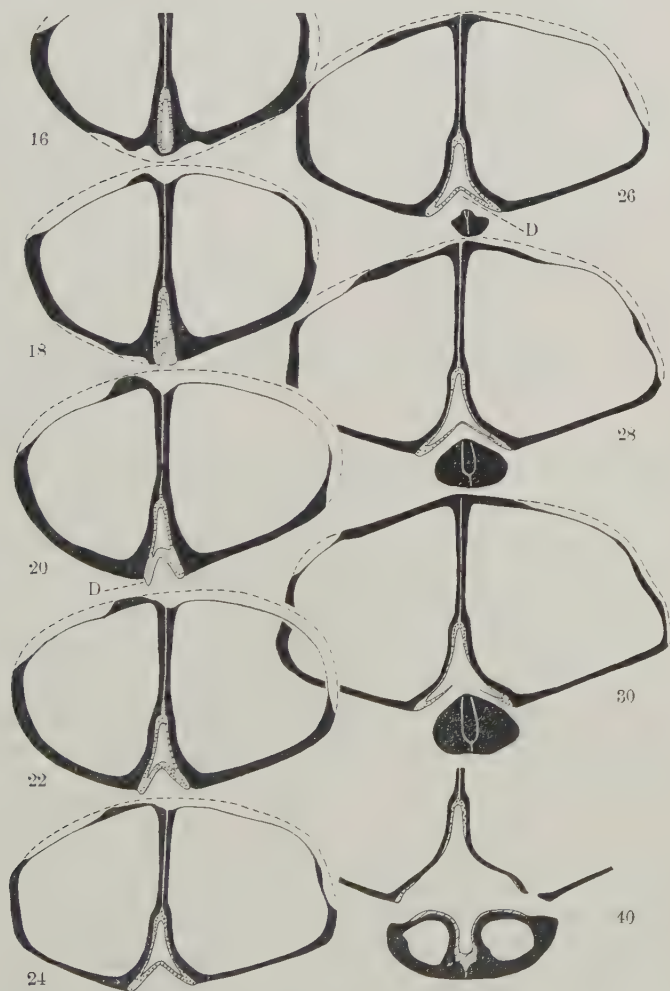
'Pseudodeltidium' of Bronn (1862) — in part, deltidium (of Hall and Clarke, 1894, Schuchert, 1897 and 1913, and Schuchert and Cooper, 1932; *non* von Buch).

The writer is very grateful to Mr. Henry Woods and Dr. O. M. B. Bulman for helpful discussion of a number of points in this section. Mr. Woods has always maintained that pseudodeltidium and deltidium should be used in their original sense [cf. Woods "Invertebrate Palaeontology" eds. I to VII (Cambridge 1893—1937), section Brachiopoda] while among American authors, pseudodeltidium has been correctly used e. g. by Girty 1908, "the Guadalupian Fauna", *Prof. Pap. U. S. geol. Surv.*, 58.

of any structures modifying the delthyrium has seldom been observed. Although Hall and Clarke (1894, pp. 247, 341—2) considered deltidial plates to be present in certain genera, such structures were not recorded by Schuchert and Cooper (1932, p. 163). The only instances in which these authors record a covering plate constricting the delthyrium are in a species of *Conchidium*, and in one species of *Harpidium*, in which they describe a rather large 'concave deltidium'. Kozłowski (1929, p. 130) has stated that deltidial plates (forming a 'deltarium discretum') are present in some species of *Gypidula*, *Clorinda*, *Pentamerella*, *Cymbidium* and *Harpidium*, and he considered that the single, concave plate in *Conchidium* and *Pentamerus* was formed by the fusion of two primitive plates composing a syndeltarium (=deltidium). He accordingly groups the Super-family Pentameracea with the Telotre mata. Kozłowski's deltidial plates evidently correspond to the slight thickenings along the delthyrial margins termed by Schuchert and Cooper (1932, pp. 163, 176) 'incipient deltidial plates' and by Booker (1927, p. 134) 'pseudo-deltidial plates'.

In the Kiær Collection of Pentamerids the material is well preserved so that it has been possible to study in considerable detail the modifications of the delthyrium, and the origin of the structures concerned. A definite pseudodeltidium is present occasionally in *Pentamerus borealis*, as a general rule in *Pentamerus laevis* [= *P. oblongus*] and in *Pentamerus* (*Pentameroides*) cf. *gotlandicus*. In *Clorinda undata* and *Stricklandia lens* there are slight thickenings of the delthyrial margins. The occurrence of these structures is described under the separate species, only the more general considerations are noted here.

The presence of a pseudodeltidium in these species has been revealed by serial sectioning. It is in specimens in which the umbones are surrounded by matrix that the structure is best preserved; the pseudodeltidium is seldom visible when individuals have been cleaned of matrix since it is so fragile as easily to be removed. In closely-spaced serial-sections or transfers it is readily seen, however, as a thin covering at the apex of the delthyrium (text-figs. 1, 5—8), while in models its true form may be appreciated, that of a triangular plate which may be flat or concave outwards in different cases (Plate V, figs. 6—7). These sections reveal also the details of its structure. The pseudodeltidium is composed of a thin layer of shell-substance which lines the spondylial cavity, and which is described in the



Text-fig. 1. *Pentamerus (Pentameroides) cf. gotlandicus*. Lebedev.

Serial transfers (S. M. C., A. 13507) at 0.15 mm intervals from the posterior end of a specimen; zone 7 c β , at Vesleøy, Ringerike. $\times 2\frac{1}{3}$. Transfers 16—40.
(For the complete series see text-fig. 8.) D = pseudodeltidium.

succeeding part of this paper. This fine layer is best developed in the posterior portion of the spondylium, it is separated from the rest of the spondylial walls by a plane of discontinuity (text-figs. 1 and 2, where this thin shell-layer is stippled). Along the anterior part of the sides of the delthyrium the free edge may be thickened and as these thickened edges are traced towards the posterior they first constrict the delthyrial opening and finally form a complete cover over the apex of the delthyrium (text-fig. 1). This cover is a single structure crossed by continuous growth lamellae, and showing no trace of a median line of suture; it is thus not formed by the fusion of two pieces growing inwards from the margin but, apparently, rather by continuous growth anteriorly from the apex of the delthyrium; it is usually limited from the cardinal-area by small grooves. In *Pentamerus laevis* the covering is flat or gently concave (text-fig. 5, transfers 18 to 27), and lies very close to the incurved dorsal umbo. In *Pentamerus* cf. *gotlandicus* it is deeply concave (text-figs. 1 and 8) owing to the pronounced incurving of the umbo, which actually projects within the delthyrial cavity. In the typical thick-shelled *Pentamerus borealis* and in *Conchidium münsteri* the same thin layer is present lining the spondylial cavity (text-figs. 2, I—II and 7, II), though in the specimens that have been sectioned it does not form a pseudodeltidium. In the species of *Clorinda* in the collection, this thin layer has not definitely been identified, and it is thus not altogether unexpected that a pseudodeltidium is never present.

The pseudodeltidium then, in these species of *Pentamerus* is composed of shell-substance continuous with that of the thin layer on the inside of the spondylium (text-fig. 1), which extends in some species even towards the anterior end of that structure. It would be in contact, in life, with the soft tissue, covering the surface of the spondylial cavity, and any increase in this layer subsequent to the formation of the spondylium could only take place by secretion by this mantle-tissue. The pseudodeltidium in these genera was thus probably formed by a small flap of the mantle which gradually extended anteriorly from the apex of the delthyrium.¹ The covering evidently served to close the posterior part of the delthyrial opening above the dorsal umbo, and owing to the incurving of the umbo there

¹ Cf. the growth of the chilidium as inferred by Thomson (1927, p. 77).

would be no room for the passage of a functional pedicle¹ (cf. text-figs. 1, 5 and 7. 1). In *P. borealis* the absence of a pseudodeltidium may possibly be explained by a closer approximation of the valves (cf. text-fig. 3, transfer 24), thereby perhaps obviating the need for such a structure. The difference, however, between this species together with *C. münsteri* and the later species of *Pentamerus* is more apparent than real, as may be seen by comparing text-figs. 1, 2 and 7. Thus, in all these forms, the thin layer lining the spondylial cavity is a constant feature and there is evidently a possibility that a pseudodeltidium might occasionally occur in *P. borealis* or in other species of *Conchidium*. It has, in fact, been observed in a *borealis-laevis* transitional form from zone 7 a at Asker (P. M. O. 53482; text-fig. 2, VI), while a deeply concave pseudodeltidium is present in the type species of *Conchidium*.

Detailed study of the typical genus of the Pentameracea gives no support to the view proposed by Kozłowski (1929, pp. 130—2) that *Pentamerus* and *Conchidium* possess a 'deltarium' [=deltidium] composed of fused deltidial plates, and that the Super-family should be grouped with the Telotremata. The covering at the apex of the delthyrium in these two genera is an undivided plate or pseudodeltidium (in the sense of Bronn, 1862); while of the genera in which Kozłowski held that the narrow deltidial plates were present, in *Clorinda* and probably also *Gypidula* this appearance is produced by a slight thickening of the delthyrial margins which never approaches the structures in e. g. Palaeozoic Rhynchonellids or Mesozoic Terebratulacea.

If the study of these genera confirms the customary grouping of the Pentameracea with the Protremata it appears also to throw doubt on the value of the pseudodeltidium and of deltidial plates in so far as they are claimed to be of different origin, as distinguishing criteria between the Protremata and Telotremata. Beecher, when he proposed his four-fold division of the Brachiopoda, stated (1892, p. 142) "that the deltidium [= pseudodeltidium of Bronn] in all species possessing it (the Protremata) is an embryological, or nepionic feature", and he describes, with reference to Kovalevskii's work on the Development of the Brachiopoda, the origin of this structure. According

¹ The pseudodeltidium in these species is never perforated near its apex for the passage of a pedicle, as is the case, for example, in the Clitambonacea.

to Beecher (1892, pp. 142—5) the 'deltidium' is present in the cephalula just before its metamorphosis; it lies on the dorsal side of the pedicle close to the dorsal valve.

"The deltidium is not, therefore, primarily, on account of its manner of origin, an integrant part of the ventral valve, but is a shell growth from the dorsal side of the body, which afterwards becomes attached to the ventral valve, and is then considered as belonging to it.

"The further growth of the deltidium around the body and pedicle, and its consequent extension into the cavity of the ventral umbo, may explain the origin of the spondylium."

(Beecher, *op. cit.*, pp. 144—5.)

The deltidial plates of the Telotremata, however, according to the same author are neanic or ephebic features appearing at a much later period of growth.

"The ventral mantle gradually extends from each side as two prolongations partially covering the opening and enveloping the proximal portion of the pedicle. As this is an extension of the shell-secreting surface of the mantle, there naturally results the formation of two plates within the deltidial area. Their structure is commonly punctate whenever the valves are punctate.

"The true deltidial plates are formed on the side of the pedicle adjacent to the hinge by extensions of the ventral mantle lobe, and begin as two plates. They are likewise expressive of maturity, and are of secondary development, while the deltidium begins as a single plate in the median line, and is eminently a primitive character in the Protremata."

(Beecher, *op. cit.*, pp. 146—7.)

Beecher's account of the formation of a pseudodeltidium was based on Kovalevskii's observations of the development of the one living genus, *Thecidium* (*Lacazella*), that is referred to the Protremata (Kovalevskii, 1874, pp. 1—40). This account has been frequently quoted by subsequent authors. It is difficult to understand from Beecher's description how a pseudodeltidium in such forms as the Pentamerids could be secreted on the dorsal side of the pedicle and 'become attached' to the ventral valve, so as to occupy the apex of the delthyrium and to be continuous with the inner layer lining the delthyrial cavity.¹ Recent authors (Thomson, 1927, p. 68; Schuchert

¹ The difficulties of Beecher's view have been fully discussed by Thomson, 1927, p. 78.

and Cooper, 1932, p. 7) define the 'deltidium' (= pseudodeltidium) as a plate growing from the apex of the delthyrium on the ventral side of the pedicle, and the latter suggest that it is formed by a flap of the ventral mantle. With regard to deltidial plates, there has been no such difference of opinion. Schuchert, 1913, Thomson, 1927, and Schuchert and Cooper, 1932, are all in accord with Beecher's view based on the study of living forms that these are secreted by extensions of the ventral mantle round the pedicle.

In *Pentamerus* and *Pentameroides* then, the pseudodeltidium was probably formed by a small fold of the mantle which grew anteriorly from the apex of the delthyrium. The structure in these genera, as in *Conchidium*, being a triangular plate attached to the sides of the delthyrium, covering the apex of the delthyrial opening, indeed, agrees closely with the original definition of a pseudodeltidium, but it occupies a different position from the (usually) rather convex covering over the anterior portion of the delthyrium (also commonly termed a pseudodeltidium), and the two may not necessarily have the same origin. However, to judge from published figures of, for example, the Clitambonitidae (Schuchert and Cooper, 1932, pls. 7 and 8) it would seem that the well developed pseudodeltidia occurring in that family could only have been secreted by a fold of the mantle surrounding the pedicle.

The condition in *Clorinda*, *Stricklandia* and *Gypidula* is different. Occasionally in these genera slight thickening may be present along the margins of the delthyrium (text-figs. 15 and 22). These are always small, never appreciably constricting the delthyrium, and do not merit the name 'deltidial plates'. In other Protremata, however, such as the Orthidae, larger, marginal plates are present constricting the delthyrium, structures which have been termed 'lateral plates' by Schuchert and Cooper (1932, p. 9). These authors cite *Glossorthis*, *Hesperorthis* and *Ptychopleurella* as genera in which they are well developed (1932, p. 23), and as far as may be seen from figures (*op. cit.*, pls. 4 and 6) these lateral plates are of the same form and occur in the same position as the deltidial plates of the Telotremata. They likewise appear to be formed by secretion by the mantle, and if they are truly homologous, Protremata evidently show occasionally a development of deltidial plates as well as a pseudodeltidium. While the presence of these structures may provide a useful guide in many cases, it would seem that distinctions between the two Orders based

on the development of pseudodeltidia or deltidial plates alone, are not of very fundamental value. Both structures are modifications of the delthyrium, both apparently secreted by the mantle. In the one case the constriction takes the form of a covering growing anteriorly from the apex of the delthyrium (*i. e.* a pseudodeltidium), in the other that of two plates which may remain separated (*i. e.* deltidial plates), approach each other, or coalesce along the median line (forming *e. g.* a deltidium [von Buch] = deltarium [Hall and Clarke], symphytium [Buckman], pseudodeltidium [Schuchert]).¹

The Septum and Spondylium.

The characteristic structure in the ventral valve of the Pentamerids is the spondylium duplex. This is composed of a pair of plates, which are in contact ventrally, where they form a duplex septum attached to the valve-wall, while dorsally they separate to build the spoon-shaped structure known as the spondylium. Within the limits of the family, the length of the septum and the length and shape of the spondylium vary considerably in different genera. Both structures may be quite short, extending only for about one—fifth or one—sixth of the length of the valve as in *Clorinda*, *Barrandella* and *Stricklandia*: the spondylium may extend for about one—third of the length of the valve (*Pentamerus borealis*), or be long, reaching from one-half to two—thirds of the length, in late examples of *P. laevis*, in *P. gotlandicus* and *Conchidium münsteri*. The septum is usually shorter than the spondylium, supporting this structure for only part of its length (*Clorinda*, *Stricklandia*); in one genus it is entirely absent (*Holorhynchus*), while it may, on the contrary, approach (*P. cf. gotlandicus*) or exceed (*Conchidium*) the length of the spondylium. In cross-section, the spondylial cavity may be roughly equilateral in

¹ It is suggested that the first name 'deltidium' von Buch should be used preferably to the others, owing to the confusion that has arisen from the different meanings attached to these terms. Thus, Beecher was somewhat inconsistent in his use of 'pseudodeltidium' and 'deltidium' (1881, p. 355; 1892, p. 142). Walcott (1912, p. 293) used the first term to denote a plate in the Inarticulata; Schuchert (1913, p. 359), as a synonym of deltarium to describe the condition of united deltidial plates.

It seems hardly necessary to distinguish by different names the case in which the line of junction of the deltidial plates is still visible from that in which it is obliterated (*cf.* Thomson, 1927, p. 68).

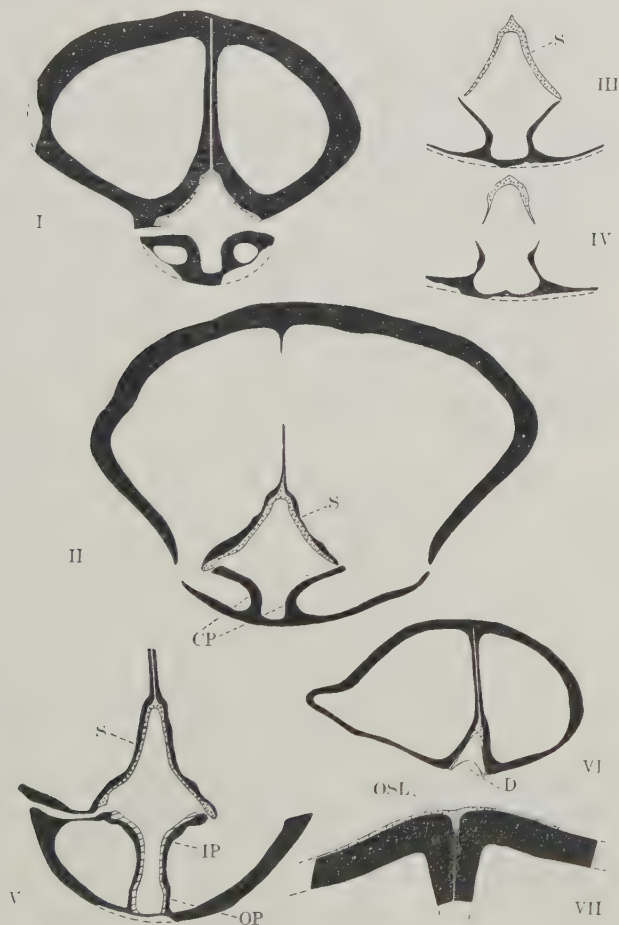
which case it presents a wide opening to the dorsal side, or narrow and with almost parallel walls, when the opening is much more restricted. Anteriorly, it terminates rather bluntly in a rounded end.

The septum is composed of calcareous material of prismatic structure; at the junction of the septum with the valve-wall, the growth-lines may sometimes be followed round into the material composing the wall. In all the species that have been sectioned, the septum may be traced as a separate structure, with its usual duplex character, as soon as the outermost layer of shell-substance has been removed at the posterior end (cf. *e. g.* text-fig. 10, transfers 12—20). The duplex character is marked by the presence of a plane of separation along the centre of the septum. This is particularly clear in *Pentamerus*, *Conchidium* and *Stricklandia lirata*; in the latter species it may be masked anteriorly, as also in *S. lens*; in this species and in *Clorinda*, the character though present, is not so well developed. The tendency for Pentamerids to split along the median plane is to some extent a measure of the degree of perfection of this duplex character. The plates composing the spondylium thicken slightly along the line at which they separate, so that the thickness of the spondylial walls is about the same as that of the septum. The walls may be further thickened at their free edges, particularly just below the corners of the delthyrium. The main part of the septum and of the spondylial walls is composed of material that appears to correspond to the inner shell-layer, but in the three species of *Pentamerus*, that have been investigated, in *Conchidium* and in some species, at least, of *Clorinda*, there is another layer of shell-material occurring as a thin sheath, lining the spondylial cavity (text-figs. 1, 2 and 7, where this layer is stippled).

The presence of this additional layer is of considerable interest. In *Pentamerus borealis* (text-fig. 2, I—IV), *P. laevis* [= *P. oblongus*] (text-fig. 7, I), and *P. cf. gotlandicus* (text-fig. 1), it occurs in the posterior region of the spondylium as a thin surface-covering, usually it is thickest at the bottom of the spondylial cavity, where it may extend a short distance ventrally along the median plane of the septum. Anteriorly, it may compose the greater part, or the whole (at least in *P. borealis* and *P. cf. gotlandicus*), of the lower end of the spondylium. The condition is similar in *Conchidium münsteri*, except that the layer is rather thicker in the posterior region (text-fig. 7, II). In *Stricklandia lirata* (forma typica) the presence of this separate layer

has already been recorded (St. Joseph, 1935 b, p. 406 and text-figs. 2 and 3), and has been termed "secondary thickening". In this species, too, the layer may be prolonged for some distance as a thin selvage along the median plane of the septum. Similarly, material of the outer shell-layer may sometimes be seen extending for a short distance inwards along the plane of the median septum (text-fig. 2, VII). The presence of this thin selvage of material was apparently first recorded by Kozłowski (1929, fig. 37, V and VI and pp. 124—5) in *Clorinda pseudolinguifera* and *Sieberella* cf. *galeata* when he gave it the name "lame intraseptale".

In the Pentamerids, the spondylial walls meet the hinge-line at the antero-dorsal corners of the delthyrium, points which function in articulation, and a comparison with the structures in the ventral valve of related Protremata, *e. g.* *Porambonites* or of Telotremata, in which there are well developed dental-plates supporting the teeth, suggests that the two structures are homologous. Thus Kozłowski (*op. cit.*, p. 125) cites the example of *Porambonites*, in different species of which there is much variation in the width of the space between the dental-plates, and compares this with the typical, duplex spondylium of the Pentamerids. On this view, each dental-plate corresponds to one of the spondylial walls, together with one side of the duplex septum. This homology must be considered when attempting to determine the method of secretion of the spondylium by the mantle. The latter normally covers the whole of the interior surface of shell, and the part of the mantle that lines the spondylium of the Pentamerids, must thus correspond to the part which *e. g.* in *Porambonites* covers the inner surface of the valve-wall between the dental-plates, as well as those plates themselves. Similarly, the mantle lining the outer surface of the spondylium and septum in Pentamerids, should correspond to the part that in other families occupies the cavities between the dental-plates and the valve-wall. The dental-plates must have been formed within infolds of the mantle, usually they are not of very great size so that a slight increase of surface area of mantle would be sufficient to cover them. In the Pentamerids, the median septum is frequently of very large size compared with dental-plates, often entirely dividing the posterior region of the ventral valve, and presumably almost the whole of the body-cavity (as in late species of *Pentamerus* and in *Conchidium*). A septum of this character could only be formed within a very large mantle-infold,



Text-fig. 2. Septum and Spondylium. (All figures $\times 2\frac{1}{3}$.)

- I—IV. — Transverse sections of *Pentamerus borealis*, zone 7 a, Ringerike. P. M. O., 58 550. V. — Transverse section of *P. laevis*, zone 7 a—b, Asker. P. M. O., 53 529. VI. — Transverse section of *P. borealis* showing pseudodeltidium, zone 7 a, Asker. P. M. O., 53 482. VII. — Transverse section of *Stricklandia lirata* forma typica, showing outer shell-layer, from uppermost Llandovery, at Woolhope, England. S. M. C., A. 13 550.

CP = crural-plates; D = pseudodeltidium; IP = inner-plates; OP = outer-plates;
OSL = outer shell-layer; S = spondylium.

and the structure of the septum may be considered to see whether it gives any indication of its mode of formation.

The internal structures in contact with the mantle would normally undergo some resorption and resecretion to be accommodated to the changing curvature, with growth of the valve-walls. In genera such as *Pentamerus* and *Conchidium* which possess a large, ventral septum (cf. text-figs. 8 and 10; Pl. V, figs. 10—11) this structure could never be covered by any small mantle-infold, but must have been secreted within an invagination of the mantle that could increase in size as along a free, growing edge. The first formed part of the septum must have been (in those forms in which it is present), the thin selvage of shell-substance occurring along the median plane (Kozłowski's "lame intraseptale"), and this appears to be continuous with the thin layer lining the spondylium (cf. text-fig. 1 and Kozłowski, 1929, fig. 7, VI). If the septum were formed within a mantle-infold with a free-growing edge, this layer should correspond to the first layer secreted by the mantle along the main shell-wall, *i. e.* the outer shell-layer, and it may be recalled that in *Stricklandia lirata* the outer layer sometimes extends for a short distance inwards along the median plane of the septum (text-fig. 2, VII). The shell-substance secreted subsequently and forming the main part of the median septum and of the spondylial walls (at least in the posterior region), will then correspond to the inner shell-layers of the valve-wall. Each of the two plates forming the septum is in contact with the mantle on its outer side only, and the plane of parting which causes the duplex character of the septum, separates the material secreted by the mantle on one side, from that on the other.

The origin and function of the spondylium may now be considered. Its duplex character distinguishes it structurally from the spondylium simplex of, for example, *Clitambonites* and *Skenidium*. In a recent discussion of spondylia, Kozłowski (1929, pp. 122—5, 126—7) derives the spondylium simplex from a pseudospondylium structure which is well exhibited in *e. g.* *Glossorthis*, by an enlargement of the genitalia owing to excessive testaceous deposit round the muscle impressions, with resulting resorption at the base of the pseudospondylium. The duplex spondylium of the Pentamerids, on the other hand, he considers to have been formed from a spondylium discretum (in *e. g.* *Huenella* and *Porambonites*), the dental-lamellae having been pushed together owing to an enlargement of the sexual glands:

"La cause de la transformation du *spondylium discretum* en *spondylium duplex* me semble résider dans l'hypertrophie des glandes sexuelles. Ces dernières, comme l'indiquent leurs impressions, souvent profondément imprimées, occupaient des espaces très grands de chaque côté. Leur développement de plus en plus grand et la pression qu'elles exerçaient sur les plaques dentales forçaient ces dernières à un déplacement progressif vers la ligne médiane, jusqu'à leur complète coalescence. A mesure que l'espace compris entre ces plaques se rétrécissait, les bases d'attache des muscles occupant cet espace étaient forcées de se déplacer sur les surfaces, internes des plaques dentales, et de s'y placer entièrement dès que ces plaques sont entrées en contact."¹

This view as to the origin of a *spondylium duplex* is not without some difficulties. In living brachiopods there are four genital glands in each animal, two on the ventral and two on the dorsal side; they may be confined within the visceral cavity or may project for some distance into the pallial sinuses of the mantle. In certain genera the glands may be fixed to the shell by ligamentous ties which produce the familiar pitted appearance in the posterior region of the valves.² In Palaeozoic brachiopods, the inner surface in the posterior region of the valves just below the umbo is often pitted; this causes a rather roughened surface on internal casts especially in the ventral valve. Such pitted areas are prominent in the Clitambonitidae, while among the Pentamerids they are often readily seen on internal casts of *Stricklandia lens* and *S. lirata* and especially of *Holorhynchus*, and are probably due to the same cause. In the Pentamerids then, it may reasonably be assumed that the genitalia occupied the same position as in living brachiopods.

The Sub-order Pentameroidea is the first large group of brachiopods that possesses as a general character a strongly biconvex shell, enclosing a considerable space between the valves. The convexity affects proportionally the posterior region of the shell, so that when compared generally with the Orthoidea, the Pentameroidea have a much larger space available for the body and its associated structures. It is thus rather difficult to see how, if this group evolved from the Orthoidea, it was an enlargement of the genitalia that caused them to press on the dental-plates and unite them into a duplex septum. It might on the contrary be enquired whether it was not enlargement of the genitalia that was the cause of the change in shape from

¹ Kozłowski, 1929, p. 126.

² Cf. Thomson, 1927, p. 13.

the typical, gently biconvex, Orthid shell, perhaps through a markedly biconvex Orthoid such as *Porambronites* to the typical biconvex Pentamerid. Any argument based on the hypertrophy of the genitalia must take into account the disposition of the other soft parts in the body cavity, of some of which in the Palaeozoic Protremata the exact disposition must be very uncertain. One might have expected, too, evidence of proportionate enlargement of the genitalia in the dorsal valve owing to the more limited space in that valve, yet the Pentamerids show no general tendency for the cardinalia to take the form of a cruralium. Nor is the disposition of the secondary thickening around the muscle impressions and in the posterior region of the shell altogether in agreement with this theory. The secondary thickening in *e. g.* *Pentamerus borealis* and *Stricklandia lirata* occurs in the posterior region of valves, filling up the cavities on either side of the ventral median septum in just the position in which it is assumed there was occurring the enlargement of the genitalia. These facts raise the question as to whether there is not some other more likely explanation of the duplex spondylium.

The general function of a spondylium is not in question. Study of the relative positions of the two valves of a Pentamerid, when these are in apposition, shows that the divaricator muscles, which are attached to the dorsal valve below the umbo and posterior to the hinge-line, must have been bedded within the spondylial cavity (cf. text-figs. 3, 5, 6, 8, and Plate V, figs. 1, 10). Similarly, the adductor muscles must have passed between the cardinalia also to the spondylial cavity.¹ The spondylium was, indeed, described by the proposers of the term as "an area of muscular implantation", and Hall and Clarke also stated that the impressions of the central adductor and lateral divaricator muscles were often clearly defined within the spondylium.² Muscle impressions in this position have seldom been observed in European material, but that the spondylium is an elevated area of muscle attachment — the opinion of all recent writers on the subject — there is no doubt.

A feature not frequently discussed in connection with the Pentamerids but characteristic of all the genera the writer has investigated — *Clorinda*, *Barrandella*, *Gypidula*, *Sieberella*, *Pentamerus*, *Pen-*

¹ The musculature is discussed at greater length in a later section.

² Hall and Clarke, 1894, pp. 331—2, 335.

tameroides, *Holorhynchus*, *Conchidium* and *Stricklandia* — is the very degenerate nature of the dentition. This is described in a later section, but, in outline, articulation may be said to take place between the posterior edges of the spondylium where they commence at the antero-dorsal corners of the delthyrium, and the margins of the inner-plates in the dorsal valve, where these separate from the hinge-line. The articulation appears to be of a much more clumsy type than in the Orthoidea, and would have been of no use in maintaining the valves together, a function that must have devolved almost wholly on the muscles. The latter thus have to bear an extra strain apart from that consequent upon their function of opening and closing the valves. Further, in the Pentamerids, with their strongly biconvex profile, the muscles, and especially the divaricators would have to be of much greater length than those in the Orthids, but for some supporting structure. The development of an elevated muscle platform, formed by the union of the dental-plates might appear to be associated with the lack of normal articulation, and the resulting extra function of the muscles. The first stage in the process may be illustrated by reference to such a species of *Porambonites* as *P. ventricosus* in which the muscles are raised far above the floor of the ventral valve, by a solid deposit of shell-material between the dental-plates, to form the structure termed by Schuchert and Cooper (1932, p. 29) a spondyloid. *Porambonites* possesses the strongly biconvex profile typical of many Pentamerids, in contrast, however, to their inefficient dentition, it has well developed teeth and sockets. The necessity of keeping the valves together has thus not arisen in connection with the muscles; and when these are elevated above the valve-floor, it is on an adventitious deposit of shell-material rather than on any special structure.

The details of the different stages by which the typical, duplex spondylium of the Pentamerids has evolved cannot yet be studied for lack of suitable material. The variation in distance between the dental-plates in different species of *Porambonites*, to which Kozłowski has drawn attention (1929, p. 127), seems most apposite in the present connection. In some species of this genus the space between the dental-plates is sufficiently large for the muscles to rest on the floor of the valve, and there is every stage from this condition to that in which the intervening space has become so narrow that the muscles

rest almost entirely on the dental-plates themselves.¹ This stage is but a very little removed from the structure in a Pentamerid possessing a low and relatively short, ventral, median septum. Whether this may indicate the general lines on which the Pentamerid, duplex spondylium has developed must remain uncertain, but the writer would regard it as a more likely mode of origin than that suggested by Schuchert and Cooper (1932, p. 161), from the Syntrophiidae. If *Syntrophia* really possesses a spondylium simplex it is difficult to see how it can, by any means, have given rise to the Pentameracea.

Once the structure known as a spondylium duplex had arisen, it underwent many modifications. Two of these are represented in the specimens in the Kiær Collection. The gradual increase in length of the spondylium and septum in the *Pentamerus* series, reaches its greatest development in the latest *Pentamerus* species and in the related genus *Conchidium* (see text-figs. 5—8, 10 and Pl. V, figs. 7—11). This is a change which tends to raise the area of muscle attachment further above the valve-floor (especially in globose forms), the greater length of the septum at the same time affording an increased support. The second modification is a tendency to reduction or even complete loss of the supporting septum. This is seen in *Clorinda* and *Barrandella* (text-figs. 11, 13, 14, 19), and it is interesting that these are also the two forms with the least degenerate dentition of all the genera that have been investigated. The genus *Holorhynchus* (text-fig. 9), with a free spondylium, occupies an isolated position and its affinities are best discussed when considering the internal structures in the dorsal valve.

The Cardinalia.²

Of the assemblage of structures which characterize the Pentameracea, the cardinalia are perhaps the most important. In such typical genera as *Pentamerus* and *Conchidium* these consist of a pair of long, crural-plates arising almost at right-angles to the valve-floor

¹ Kozłowski, *op. cit.*, p. 127. For a description of the internal structures of *Porambonites* see Noetling, 1883, pp. 360 ff.

² This term, apparently introduced by Thomson (1927, p. 83), was used by Schuchert and Cooper (1932) in descriptions of Orthoidea and Pentameroidea. It may conveniently be applied in the Pentamerids to the assemblage of structures in the dorsal valve, which are often loosely called 'crural-plates' — a usage which does not conflict with the original definition.

and beyond which there may project the brachial-processes. The crural-plates frequently have a rather distinct, three-fold division into inner-plates, bases of the brachial-processes and outer-plates¹ (cf. text-figs. 8 and 15); the latter either join the floor of the valve or unite with each other, in which case the cardinalia form a cruralium (text-fig. 8). The inner-plates and outer-plates together form the greater part of the cardinalia, for the brachial-processes though long, are relatively narrow.

The inner-plates usually diverge from one another, being convex inwards to the centre of the valve; anteriorly the divergence may decrease so that the plates become almost parallel. Their free (inner) edges are often directed towards the margins of the spondylium and in different cases they lie a little inside (text-fig. 6) or outside (text-fig. 3) the latter. Just below the umbo they may have formed part of the area of attachment of the divaricator muscles, but anteriorly they become very thin. At the point at which they separate from the valve-wall their free edges may abut against the thickened margins of the spondylium, the arrangement serving for articulation. Their dorsal edges are fused with the bases of the brachial-processes. These are usually sub-parallel, and not always clearly separated from the outer-plates; they are less high² than the inner- or outer-plates, but extend beyond the latter often to about the end of the spondylium as free brachial-processes. The outer-plates lie in the same plane as the bases of the brachial-processes with which they are fused, and they extend to the valve-floor. They are generally rather thin, and parallel, but may be divergent (*Clorinda*: text-figs. 15, 18) or convergent (*Pentameroides*: text-fig. 8) and in the latter case they frequently form a cruralium. The development of a cruralium appears to be due to the gradual approximation and final union of the outer-plates, but in the one form (*Pentameroides* cf. *gotlandicus*) in which it has been studied in detail, it is interesting that even in their earliest stages of growth, embedded in the thickening of the shell-wall at the

¹ These correspond respectively to the structures lettered Ip, BBP and Ops (or Op and Ms) in Figs. 26—28 of Schuchert and Cooper, 1932, p. 164: but in their discussion of the terms proposed by Leidhold (1928, pp. 51—3) these authors describe the cardinalia as composed of (1) inner-plates, united with (2) outer-plates which are separated by (3) a crural band or longitudinal thickening from (4) the septal or supporting-plates, united with the valve-floor.

² This refers to their dimension in a dorsal-ventral direction.

posterior end of the valve, the outer-plates are always united and retain no trace of the stage when they were separate (cf. text-fig. 1, transfers 26—30).

The genera *Clorinda*, *Holorhynchus* and *Stricklandia* depart from this standard type. In the first of these, the cardinalia are small and divergent, with very short inner- and outer-plates. Some species (e. g. *C. kjerulfi*) show no clearly defined junctions between the plates, and the outer-plates and the bases of the brachial-processes appear often to be fused together (text-fig. 13). *C. undata* possesses widely divergent outer-plates, brachial-processes that are concave to each other, and inner-plates that are often rather longer than the outer-plates. The edges of the bases of the brachial-processes often project slightly from the plane of the inner- and outer-plates to form small carinae (text-fig. 15). A closely similar arrangement has been described in species of '*Barrandina*' (= *Clorinda*) from Australia (Booker, 1927, pp. 134 ff.).

In *Holorhynchus*, the structure is much less typically Pentamerid (text-fig. 9). Slender, rod-like, inwardly-inclined, brachial-processes occur, situated near to the valve-wall. These are attached posteriorly to a pair of diverging plates that approach the edges of the spondylium. These plates evidently correspond in position to inner-plates, but there are no traces of structures representing the outer-plates, since the bases of the brachial-processes arise very close to the valve-wall (text-fig. 9, transfers 100 to 124). The arrangement in *Stricklandia* is similar. In this genus (text-figs. 20—21, 23) the structures in the dorsal valve consist of slender, inwardly-inclined brachial-processes (= crural-processes) which are fused to a second pair of plates (= outer pair of plates, of St. Joseph, 1935 b, p. 413) directed towards the edges of the spondylium. A comparison of text-figure 21, transfers 23 to 33 with text-figure 9, transfers 104 to 116 illustrates the resemblance. In both these genera it would seem that the plates lying nearest to the spondylium correspond to the inner-plates of typical Pentamerids, while the outer-plates are either absent or represented in part by the bases of the brachial-processes. The internal structures of *Clorinda* represent a possible intermediate stage, for in some species of that genus there is a tendency for the outer-plates to be reduced, and not clearly separated from the bases of the brachial-processes, while the inner-plates may be somewhat lengthened (cf. text-fig. 14, transfers 20 to 24 and text-fig. 13, transfers 28 to 34

with text-fig. 21, transfers 23 to 29 and text-fig. 20, transfers 22 to 28).

The cardinalia in *Stricklandia* are thus not so anomalous as has hitherto been thought. They are very similar to the arrangement in *Holorhynchus* and though far removed from the typical Pentamerid development, the structure in some species of *Clorinda* may provide a possible, morphological intermediate. *Stricklandia* can hardly have given rise, however, directly to *Pentamerus* as Kiær considered (1908, p. 500) for the differences in internal structure are relatively great.

A thin layer of lamellar shell-material covers the inside of the cardinalia in some specimens of *Pentamerus laevis* and *P. cf. gotlandicus*, and appears to be of the same nature as the layer lining the spondylial cavity in those species. It is indicated by shading in text-figs. 1, (40) and 2, V. It may be present in other species of *Pentamerus*, and something evidently very similar was recorded by Hall and Clarke (1894, p. 238, fig. 171 in a specimen of *P. 'oblongus'* [= *laevis*]).

Musculature.

Muscle impressions are seldom well preserved in the Pentameracea. They are best studied in internal casts, and consequently this collection of material in which the shell-substance is largely present has yielded little, direct information. Evidence as to the position of the muscles, however, is also afforded by the relations between the various internal structures in the shell; relations which may easily be seen in the scale-models that have been constructed of the various species. Information derived from internal casts of species of *Stricklandia* and of *Clorinda undata* in which the muscle-scars are occasionally clear, shows that there is a median grouping of adductor-scars rather towards the posterior of the dorsal valve, while on the floor of the ventral valve, muscle-scars have never been observed. The muscles are usually considered to have been attached in this valve to the inside of the spondylium, in which position scars were recorded by Hall and Clarke (1894, pp. 331—5).

In the dorsal valve the position of attachment of the divaricator muscles must have occurred posterior to the hinge-line. A cardinal-process is always rudimentary or absent in this family and the area of attachment appears to have lain partly within the posterior end of the cavity defined by the cardinalia, and partly perhaps on the

inner-plates themselves, in species such as *P. borealis* and *P. gotlandicus* in which these structures diverge strongly from one another. From such a position the divaricator muscles can only have extended to the inside of the spondylial cavity, as is demonstrated by a study of serial drawings (text-figs. 3, 5, 6, and 8) showing the relative position of the cardinalia and spondylium in life. Similarly, if the evidence of *Stricklandia* and the occasional presence of faint impressions on the floor of the valve, between the cardinalia in species of *Pentamerus* may be taken to demonstrate a normal grouping of adductor scars in this position, the arrangement of the internal structures shows that the course of the adductor muscles can only have run to the inside of the spondylium. The small, median ridge that occurs on the floor of the dorsal valve between the outer-plates possibly separated muscle impressions, just as did the rather similar ridge down the back of the spondylial cavity in *Stricklandia*. In *Pentameroides*, in which the cardinalia unite to form a cruralium, the area of muscle attachment was evidently elevated above the floor of the dorsal valve just as in the ventral.

Mantle Impressions:

Pallial and Genital Markings.

Traces of the soft parts other than muscle-scars can only seldom be studied in the Pentameridae and of these, the clearest impressions are usually the genital or ovarian markings. That the mantle, which lines the whole of the interior of the shell,¹ might retain its function of shell-secretion throughout the greater part of the life of the animal is illustrated by several species in this collection. Continual adsorption and re-secretion of shell-material must have occurred during the early stages of growth in order to accommodate the septum and spondylium to the changing curvature of the valves. In *Pentamerus borealis* and *Stricklandia lirata* which possess a greatly thickened shell in the posterior region, internal structures such as the septum in the ventral valve, or the cardinalia in the dorsal valve, can be traced embedded in the shell-wall almost to the exterior surface. At the time of their formation these structures must have been in

¹ The term 'mantle' is here used to include the dorsal and ventral surfaces of the body-wall.

contact with the mantle (cf. St. Joseph, 1935 b, p. 413), and the shell-material in which they are embedded must consequently be a later secretion.

One specimen of *P. gotlandicus* that was chosen for serial-sectioning is especially interesting in this connection. The median septum in this species is usually rather thin, especially towards the anterior, and in this individual both the septum and the left spondylial wall had fractured and been subsequently mended by additional secretion of shell-material, evidently by the mantle. The lines of fracture are now marked by thickenings due to this extra shell-substance (cf. text-fig. 8, showing an expansion on the left side of the septum).

Two individuals of *Stricklandia lens* show a peculiarity in the ventral valve. In these (cf. text-fig. 20, transfers 12 to 20 and text-fig. 22), there occurs for a short distance a second septum on the right side of the normal, median septum and there is also a trace of another septum on the other side (text-fig. 20, transfers 12—14). Evidently in these specimens there was a tendency to form more than one mantle-infold, and such conditions perhaps give some indication of the mode of formation of the structure in some Clitambonacea described by Öpik as a spondylium triplex.

Pallial Markings: Markings of the pallial sinuses have rarely been observed in this group of Brachiopods and of the specimens under immediate consideration have been described only in *Clorinda undata*. In large forms of that species, they frequently appear as irregular, longitudinal ridges. One specimen (S. M. C. A. 13551 from the Llandovery of Mathyrafal) exhibits a much more definite arrangement of main and auxilliary trunks, and although not included in the Kiær Collection, may for its general interest be described here. It is an internal cast of a ventral valve, showing (text-fig. 16) two antero-laterally directed trunks near the end of the median septum. Of the two branches formed at each first bifurcation, one is directed anteriorly where it dichotomizes further, the other towards the lateral margin. The arrangement is evidently closely similar to that in a specimen from the same locality figured by Davidson (1867, pl. xix, fig. 8 B).

Genital Markings: The impressions of the ligament-attachments, which bind the genital glands to the valve-wall usually produce a rather pitted appearance on the inner surface of the valves. Such

an effect is not uncommon in the Pentameracea; it is best studied in internal casts and may frequently be seen in species of *Stricklandia* over quite a large area at the posterior end of the shell, especially in the ventral valve. In *Holorhynchus* these impressions are very strongly developed, the whole of the inner surface of the ventral valve and also the sides of the spondylium being covered with small rugosities.

Stratigraphical Considerations.

The Pentamerids range in southern Norway between zones 5 b and 8 c, but it is from horizons 6 c, the maximum of *Stricklandia lens* to 7 b, the maximum of *Pentamerus laevis*, that they attain their greatest abundance. Their distribution is indicated in the following table:

Stratigraphical Distribution of Species.

Zone 8 a—c	<i>Clorinda malmøensis</i> , new species.	
» 7 c	<i>Pentamerus</i> (<i>Pentameroides</i>)cf. <i>gotlandicus</i> Leb. } especially in <i>Stricklandia lirata</i> (J. de C. Sow.) } 7 cβ. <i>Clorinda undata</i> (J. de C. Sow.), small, late variety.	
» 7 b	<i>Pentamerus laevis</i> (J. Sow.), very common.	
» 7 a—b	Early forms of <i>Pentamerus laevis</i> (J. Sow.), with <i>borealis-laevis</i> transients.	
» 7 a	<i>Pentamerus borealis</i> (Eichw.), abundant.	
» 6 c	<i>Stricklandia lens</i> (J. de C. Sow.), maximum development in 6 cα. Occasional, early examples of <i>Pentamerus borealis</i> (Eichw.). <i>Clorinda undata</i> (J. de C. Sow.), rarely.	
» 6 b	Early forms of <i>Stricklandia lens</i> (J. de C. Sow.). <i>Clorinda undata</i> (J. de C. Sow.) } maximum development in	
» 6 a	<i>Clorinda undata</i> (J. de C. Sow.) }	6 a—b.
» 5 b	<i>Holorhynchus giganteus</i> Kiær. <i>Conchidium münsteri</i> , new species (Kiær MS). <i>Clorinda kjerulfi</i> (Kiær).	

The three species from zone 5 b are as yet known from no other region. *Clorinda undata* which ranges through the whole of stage 6, and though less commonly through part of 7, is most abundant in the eastern development as at Malmøy and Asker. It attains its maximum about the top of 6 a, just before the first appearance of *Stricklandia lens*. The latter species is characteristic of zone 6 c being particularly common in the lower part of the zone, again in the eastern development. The earliest specimens of *Pentamerus* occur in 6 cβ at Asker, but the first general appearance of *Pentamerus borealis* is in 7 a in the western development at Ringerike, Hadeland

and Holmestrand (cf. Table I). The typical, thick-shelled *P. borealis*, indeed, does not occur at Asker and Malmøy. *Pentamerus laevis* in 7 b has the widest distribution of any of these species being known from all the different districts, even at Mjøsen in the north. Above this horizon the distribution of the Pentamerids becomes more restricted; *Pentamerus gotlandicus* and *Stricklandia lirata* which characterize 7 c β are most abundant in the western districts and unknown at Malmøy, while in the succeeding stage 8, *Clorinda malmøyensis* from 8 a and 8 c is almost the only species recorded.

It will be seen that the Pentamerids are typical of the eastern development in stage 6, being almost absent in the western districts and that they occur abundantly in the west (Ringerike and Skien and Porsgrund) for the first time at the base of stage 7, the "*Pentamerus*-kalk" of 7 b being a rather constant horizon. Above this their distribution becomes more restricted, but this time to the western development. This distribution is directly related to the conditions prevailing in the several areas when the rocks were formed. In stage 5 a considerable shallowing of the sea took place in the Oslo region; a fact that is indicated by the occurrence at horizon 5 b of such shallow-water deposits as sandy and oolitic limestones, pebblebeds with a matrix of oolitic limestone and even a breccia facies (Kiær, 1901, pp. 96—8). At the top of 5 b a depression of the sea-floor commenced and continued through stage 6. The effect is least marked in the Ringerike and Hadeland districts in the west, where calcareous sandstone and shale and arenaceous limestone are the commonest rock-types (Table I); ripple-marked surfaces occur, and the rocks seem to have been formed at no great distance from a shore line. In the east, much deeper-water conditions prevailed, mudstones with some calcareous beds and shales being accumulated, and it is these rocks that yield *C. undata* and *S. lens* most abundantly. The limestones and mudstones of stage 7 with *Pentamerus*, in the eastern district, would seem to be of slightly shallower-water formation, but deeper-water conditions commence again in 7 c and continue in the graptolite shales of 8 a and b. In the west, especially at Ringerike and Skien and Porsgrund relatively shallow-water conditions persisted, and the rocks are mostly calcareous. The shell banks of 7 a composed of *Pentamerus borealis* valves would appear to have been formed under the action of relatively strong currents, and this together with the presence of ripple-marked surfaces may

Table I.

Zone	Southern	
	Western development I Ringerike	Eastern II. Malmøy ¹
9 a—g	Limestones and some shale with Ostracods, c. 250 m	(At Holmestrand, limestones with Ostracods, 106—116 m)
8 d	Dark limestone, 2—12 m	"Malmøykalk", 10—15 m
8 c	"Wenlockkalk", coral-reef limestone & shale, 4—25 m	<i>Rhynchotreta cuneata</i> limestone, 6—8 m
8 b	Arenaceous limestone, 45 m	Beds with <i>Monograptus</i> , c. 80 m
8 a	Greenish shale and arenaceous limestone, 70 m	
7 cγ	Upper red <i>Crotalocrinus</i> shale, c. 35 m	Limestone and shale with <i>Crotalocrinus</i> , c. 50 m
7 cβ	<i>Stricklandia lirata</i> beds, or upper coral limestone, 25 m	
7 cα	Lower red <i>Crotalocrinus</i> shale, 20 m	
7 bβ	Lower Coral limestone, 17 m	Beds with <i>Pentamerus laevis</i> , 35 m
7 bα	Limestones with <i>P. laevis</i> (= <i>oblongus</i>), 25 m	
7 a	Limestones & shale (<i>P. borealis</i> beds), 10 m	Grey <i>Pentamerus</i> limestones, 30 m
6 c	Arenaceous limestone and shale, 45 m	Shale & limestone with <i>S. lens</i> , 30—40 m
6 b	Calcareous sandstone, 50 m	Shales, c. 50 m
6 a	Calcareous sandstone and shale, 20 m	Shales & mudstones with <i>C. undata</i> , 50—60 m
5 b	Calcareous sandstones, c. 45 m	Calcareous sandstones with conglomeratic 'pebble-bed' facies

¹ The succession at Holmestrand (III) is generally similar to that at Malmøy in stage 6, and to that at Asker and Bærum in stages 7—8.

Norway		British shelly facies
development V. Asker and Bærum ²	Northern development VII. Mjøsen	
Limestones and calcareous shales, c. 200 m	Red and yellow sandstones	Ludlovian
"Malmøykalk", 8–10 m	Thick succession of red and yellow sandstones	Wenlockian
<i>Chonetes</i> beds, 30 m		
Shales with <i>Monograptus</i> , c. 90 m	Calcareous sandstones with shale bands	
<i>Stricklandia lirata</i> beds, or upper coral limestone, c. 50 m	Shales with graptolites, 80–100 m	Upper Llandoveryan
Red <i>Crotalocrinus</i> shales, 12 m		
Lower Coral limestone, 30 m	Lower Coral limestone, 9–10 m	
<i>Pentamerus</i> limestone, c. 60 m	<i>Pentamerus</i> limestone, 9–15 m	
Calcareous shale & limestones, 60–70 m	Sandstones, calcareous sandstones & shales, c. 9–30 m	? Middle Llandoveryan
Calcareous sandstones and shales, c. 42 m		
Mudstones & calcareous beds, c. 65 m		
Calcareous & sandy beds with oolitic limestone & breccia facies	Calcareous mudstones & shales; arenaceous towards the top	? Lower Llandoveryan

² In stages 7–9, the succession at Asker and Bærum is partly eastern, partly western in character.

be taken to indicate quite shallow-water conditions. The limestones of 7 c β with large, isolated valves of *Stricklandia lirata* and *Pentamerus gotlandicus* belong to the same facies. Finally, the tendency to deeper-water conditions in the lower half of stage 8, which is so marked at Malmøy, is found also at Ringerike, but not to the same degree. The fauna of these rocks is thus closely related to the varying lithology, which appears to be a direct expression of the changing conditions under which the rocks were accumulated.

The details of the stratigraphy are given in Table I, which is based on Kiær's monograph (Kiær, 1908, pp. 472—3, 494—5, 576—7). The inclusion of zone 5 b in the Silurian, a course later adopted by Kiær and now commonly accepted, is justified by its faunal content, especially the three Pentamerid species. The suggested correlation with the British shelly-facies differs from that proposed by Kiær in that stage 6 is equated with the Middle rather than the Lower Llandovery. This seems to be indicated by the distribution of the shelly fossils. Thus, *Clorinda undata* and *Stricklandia lens* characteristic respectively of zones 6 a β and 6 c α in southern Norway, attain their maximum in Britain at the top of the Lower Llandovery and in the Middle Llandovery. *Meristina crassa* the zone fossil of 5 b is commonest in Britain at the top of the Lower Llandovery, while the recorded occurrence of *Atrypa reticularis*, *Leptaena rhomboidalis* and *Strophomena euglypha* from 6 a onwards support this view. The beds with *Meristina crassa* in Britain occur nearly 2000 feet above the Ordovician, and it would seem as if there were a break of some importance between 5 a and 5 b, for the former which has yielded *Trinucleus* and Asaphids must certainly be Ordovician.

At higher horizons the maximum of *Pentamerus oblongus* in 7 b and of *Stricklandia lirata* forma *typica* in 7 c β are useful guides in correlation, and appear to correspond respectively to the *Pentamerus* limestone of Shropshire and the topmost beds of the Llandovery.

Description of Genera and Species.

The History of the Genera *Conchidium* and *Pentamerus*.

These two names are so familiar and so well established in the literature of the Silurian Brachiopoda that it is the more regrettable that neither has ever received proper definition in accordance with

the International Rules of Zoological Nomenclature. The early descriptions of the Pentamerids are greatly confused, but the histories of these two forms have so much in common that they may conveniently be considered together. The treatment is purposely detailed, in the hope that if the nomenclature be stabilised in the light of a full discussion, later writers may conform to the system of names here adopted, and that further confusion may be avoided.

The most recent treatment of these genera (Schuchert and Cooper, 1932, pp. 177, 181) ascribes *Pentamerus* to J. Sowerby (1812, p. 73, pl. 28) with genolectotype (Hall and Clarke, 1894, p. 236) *P. laevis* J. Sow. and *Conchidium* to Linnaeus (1760 [*sic, err. pro* 1768], p. 163) with genotype *C. biloculare* Linn. 1753 (pl. 5, fig. 8) — ascriptions which both require qualification. The earliest reference to *Conchidium* appears to be in Linnaeus' *Museum Tessinianum* 1753 [p. 90, Tab. V, figs. 8 A and B], where, under the entry *Conchidium biloculare* there is a concise and appropriate description in Latin, a reference for localities to "Oelandia, Gotlandia *frequens*", and two recognizable figures of a ventral valve, the one showing a spondylium supported on a long septum. In considering the origin of both genus and species this reference cannot be taken into account, for the publication antedates 1758, the accepted starting-point for zoological nomenclature under Article 26 of the International Rules.¹

The next reference to this form is in Linnaeus' *Systema Natura* Ed. XII, Tomus III, 1768, p. 163, when he again gives a short description, as follows:

"41 Helmintholithus

Conchidium 3. *Helminthol. Patellae? bilocularis* *Conchidium*. Mus. Tess. 90, t. 5. f. 8. *Habitat in Mari Balthico; certe petrificatum in Oelandia, Gothlandia frequens; deperditus.*

Testa antiquata fere Cardii edulis, solitaria, repleta calce solida; facillime findatur longitudinaliter in partes duas aequales; at vero, ubi non farcta calce a parte inferiore s. interiore, sepimento longitudinali dividitur in duo loculamenta."

¹ The references to this code are to the reprint of the International Rules of Zoological Nomenclature, in *Proc. biol. Soc. Wash.*, Vol. 39, pp. 75—104 (1926), hereafter referred to as the "International Rules", and the Articles are cited as numbered there.

There would seem to be several ways of interpreting the string of names that follows *Helmintholithus*, but following Sherborn (1902, p. 236), the usage is to be regarded as trinomial, "*Conchidium Helmintholithum*" constituting the species.¹ This diagnosis then, the reference commonly cited as the original description of *Conchidium*, must be rejected under Articles 2 and 25 (b) of the International Rules. Such a course means that the next earliest binomial usage after this date must be accepted as the original description. This seems to be in Hisinger's "*Minerographiske anmärkningar öfver Gottland*" (1799) p. 285:

"Anomia bilocularis, testa obovata convexa multisulcata, nate incurvata; valva longiore sepimento longitudinali in duo loculamenta divisa.

Finnes vid Klinteberg til myckenhet både med och utan hopsittande parskal, och är den samma hvars ena skal i Syst. Nat, T. III. 101. 33. β blifvit räknad til *Helminth. Patellaria. Conchidium*."

That Hisinger was referring to the same form as Linnaeus is evident, the elements of his diagnosis can be recognized in Linnaeus' description. Further, "a multi-ribbed, fossil shell, with the larger valve divided by a long, median septum into two chambers" does not admit of many interpretations. There is also a reference at second-hand (through the *Systema Natura*) to a figure, while a locality is cited; all this must constitute "an indication, or a definition, or a description" within the meaning of Article 25 (a) of the International Rules [cf. also Opinion 1 (A) *Ibid.* p. 91].² This description then must be taken as the original diagnosis of the species and must, further, have priority over all subsequent accounts in determining to which genus the species should be attributed. Hisinger referred the species primarily to *Anomia* and stated that it had also been reckoned as *Helminth. [olithum]*, *Patellaria [err. pro Patella]* and *Conchidium*.

At that date a great number of both living and fossil bivalves were included under the names *Anomia* and *Anomites: bilocularis*

¹ This is by no means the only case; Sherborn gives analogous interpretations for similar strings of names occurring elsewhere in the *Systema Natura*.

² This case does not come within the scope of Opinion 5 (*Ibid.* pp. 91—2) as Hisinger's definition is not a reprint from the *Museum Tessinianum*, but a new interpretation.

is not the type species and the name *Anomia* had even been used already by Linnaeus himself (1761, pp. 520—21) in a more restricted sense [for *A. craniolaris* and other living forms, there classed under Vermes (Testacea)]. It has since been restricted as a genus of Lamellibranchs (*Anomia* Müller ex Linn.). *Bilocularis* hence cannot now be referred to *Anomia*, but in determining to which genus it should be ascribed the three generic names cited by Hisinger have priority over all others, and it was open for any later author to choose between them in accordance with the International Rules. This choice has strictly never been made. Wahlenberg (1819, p. 67) quotes (apparently) the same species as *Anomites conchidium* and refers to Linnaeus (1753) and Hisinger (1799). Dalman (1828, p. 125) proposed a new genus *Gypidia* with *conchidium* as a specific name: his synonymy, description and figures show that it is the same form as that termed by Linnaeus (1753) *Conchidium biloculare* or by Hisinger (1799) *Anomia bilocularis*. The name *Gypidia conchidium* was subsequently adopted by Hisinger himself (1837, pp. 74—5). Later authors perpetuated the error by quoting the same species and referring them to different genera, chiefly *Pentamerus* J. Sowerby and *Conchidium* auctt. *Conchidium* was redefined by Oehlert (1887, p. 1311), and by him attributed to Linnaeus 1760 (*err. pro* 1768) the trinomial usage in the *Systema Natura* being waived.

Any choice made now between the three generic names to which Hisinger (1799) stated the species *bilocularis* had been referred, must be guided by the subsequent history of these terms as well as by general convenience. Of these three names, *Helminth. [olithum]* does not appear to be recognized as an existing genus. It was originally defined trinomially in the *Systema Natura* and had not been redescribed, at least up to 1850. *Patella* has already been restricted as a genus of gasteropods [*Patella* Linn. emend.]. The remaining name *Conchidium* is available and has, indeed, nearly always been used in this sense, although with incorrect ascription to Linnaeus on the basis of his trinomial description. Such a choice of name is thus most compatible with the subsequent history of the term and the genus is redefined on pp. 125—6 of the present paper and ascribed to Hisinger 1799, with genotype *Conchidium bilocularis* Hisinger 1799, the single original species mentioned by Hisinger.

This interpretation of the history of *Conchidium* is directly relevant to the history of the genus *Pentamerus*. The name *Pentamerus* was proposed by J. Sowerby (Aug. 1813, p.73*) his generic definition being as follows:

Pentamerus.

"Gen. Char. An equal-sided inequivalved bivalve, one valve divided by a longitudinal internal septum into two parts, the other by two septa into three parts or valves. Beaks incurved, imperforate."

He referred to this genus three new species — *Pentamerus knightii*, *P. aylesfordii* and *P. laevis* (*Ibid.*, pp. 73*—76*). No selection was made as to a genotype. Of these three species *P. knightii* is certainly referable to the then existing genus *Conchidium* Hisinger, while *P. aylesfordii* is now generally regarded as a synonym of *P. knightii*; in any case, it also is referable to *Conchidium*. Thus when Davidson (1853, p. 97) close *P. knightii* as the genolectotype of *Pentamerus* J. Sowerby, he selected a species that should have been referred to an already existing genus. The remaining species *P. laevis* was chosen as genolectotype by Hall and Clarke (1894, pp. 236—7). J. Sowerby's original description of this form is as follows (*Mineral Conchology* p. 76*, pl. 28, bottom, right-hand figure):

"Pentamerus laevis,

Spec. Char. Smooth, triangular, front rounding, beaks incurved. Much less gibbous than either of the last [i. e. than *P. knightii* and *P. aylesfordii*]; free from furrows, but having slight depressions over the septa; length generally less than an inch.

Not having found this in a perfect state, although I have had stones including hundreds of specimens, I have been doubtful whether I ought to admit it. The Rev. Dr. Abbot, of Bedford, in May, 1812, was so kind as to bring me pieces of rolled Limestone, with these small dividing shells, from near Hopton Court, where he thought they appeared to be left by the swell of the river Teme, and formed a bank three feet or more high.

Sometimes I think there are two species in the stone, a smooth and a furrowed one, but better chance than I have had must determine this; at the same time the formation is distinctly characterized.

The same stones contain the remains of Madrepores. The specimen figured is from Bildwas, Shropshire, collected by A. Aikin, Esq."

His figure shows a portion of a small ventral valve, rather triangular in outline, broken at the posterior to expose a long, median duplex septum.

It will be seen that while the majority of his specimens were from drift,¹ and thus assignable to no particular horizon, the figured example was from Buildwas, Salop. This latter place then, must be taken as the type locality, a conclusion of much interest, since the only beds exposed anywhere in the vicinity of Buildwas that contain Pentamerids are the 'Pentamerus Beds' and Purple Shales of the Upper Llandovery,² so that it was probably from this broad horizon that Sowerby's specimens came. Unfortunately, the original figured specimen appears now to be lost,³ but although J. Sowerby's description is somewhat lacking in precision a study of his figure as well as of parallel material in the J. de C. Sowerby Collection leaves no doubt as to the characters of the species that he was describing. The figure shows the ventral valve of a smooth Pentamerid with (for its size) a long, median, duplex septum, while the specimens from the J. de C. Sowerby Collection labelled *Pentamerus laevis* in a contemporary hand⁴ are forms which today would normally be referred to *Pentamerus oblongus* J. de C. Sow. 1839. Further, J. Sowerby's description of *P. laevis* is almost entirely applicable as a concise definition of *P. oblongus* J. de C. Sow. 1839,⁵ the only

¹ The Hopton Court cited by Sowerby is most probably the Country House of that name situated six miles WSW of Worcester, England and about one mile south of the river Teme.

² Cf. Whittard, *Quart. J. geol. Soc. Lond.*, vol. LXXXIII (1927), p. 745, pl. lvii.

³ It is not preserved with the rest of the J. Sowerby Collection in the British Museum (Natural History), London, nor in the Collection of the Geological Survey, London.

⁴ The specimens in question are B. M. (N. H.) BB 126 (some three specimens in a block), which have on the label the date 1835 and in a contemporary hand "Pentamerus laevis. Long Mynd, Salop." BB 123, also dated 1835, has in the same handwriting "Pentamerus. Soudley, Salop". Further specimens in the J. de C. Sowerby Collection are BB 124 labelled "Boocaun. Cong." [Galway, Ireland]; BB 125 labelled "*P. knightii*, Madeley Coal Pits"; this specimen appears to be the original of pl. 19, fig. 9 (top figure) of "The Silurian System" 1839, there described as *Pentamerus laevis*; and BB 127 labelled "Marbury: R. I. M." All these specimens would today normally be referred to *Pentamerus oblongus*. The handwriting on BB 123 and 126 may well be J. de C. Sowerby's.

⁵ *Pentamerus oblongus* J. de C. Sowerby 1839 is also invalidated as a homonym of *Pentamerus oblongus* Pander 1830, p. 94, though it may be seen from Pander's figures (*Ibid.* Tab. ix, fig. 5) that his species would certainly not now be referred to *Pentamerus s. s.* This produced the confusing result that there are identical specimens in the older collections, some labelled *Pentamerus conchidium* (after Pander) and others *Conchidium pentamerus* (after *e. g.* de Verneuil, 1845).

smooth *Pentamerus* (*sensu stricto*) now recognized as occurring in the British Silurian; the small average size of J. Sowerby's specimens was probably due to their being young individuals. When it is added that the identity of the two forms was expressed in an almost contemporary opinion¹ little possibility of doubt remains that *Pentamerus oblongus* J. de C. Sowerby 1839 is a synonym of *Pentamerus laevis* J. Sowerby 1813. The former name then must be rejected in favour of the latter under Article 25 of the International Rules (The Law of Priority). *Pentamerus laevis* J. Sowerby 1813 should also become the genotype of *Pentamerus*, on account of its being the one valid species referable to the genus at the time the latter was proposed.

The changes of nomenclature that are involved may conveniently be summarized here. The genus *Conchidium* which is to be retained, must be referred to Hisinger 1799 (ex Linnaeus 1768) rather than to Linnaeus direct. *Pentamerus laevis* J. Sowerby 1813, is a specific name that must replace the commonly used name *P. oblongus* J. de C. Sowerby 1839, the latter being rejected as a synonym. The genus *Pentamerus* J. Sowerby 1813 is apparently governed by Davidson's choice (1853) of *P. knightii* as type, though it is arguable whether in fact he conformed to the strict interpretation of Article 30 II (g) of the International Rules [cf. also Recommendation III (k)]. If his selection were allowed to stand, *Pentamerus* J. Sowerby 1813 would become a synonym of *Conchidium* W. Hisinger 1799, and a new generic name would be required for Pentamerids of the *P. laevis* group.²

¹ J. de C. Sowerby 1839, briefly described and figured *P. laevis* (p. 641, pl. 19, fig. 9) as well as proposing the name *P. oblongus* (p. 641, pl. 19, fig. 10) and evidently considered the forms as quite distinct. McCoy (1852, pp. 209, 211) also accorded the species separate descriptions, but the differences he mentions depend on the size of the individuals; but it was Davidson (1867) who was really responsible for perpetuating the error. He quoted in full (p. 153) J. Sowerby's description of *P. laevis* and stated "It is now admitted by most palaeontologists that *P. laevis* Sow. is the young of *P. oblongus*, and if it were necessary to strictly adhere to the rules of priority, James Sowerby's name published in August 1813, would perhaps require to be adopted in preference to that of *oblongus*, given to the adult shell by Mr J. de C. Sowerby in 1839". [Cf. also Davidson's footnote on p. 158, *Ibid.*]. Salter was of the same opinion (cf. Salter 1866, p. 276, and 1873, p. 80, "*P. laevis* is the young only" [of *P. oblongus*]).

² A recent author would interpret the genus *Pentamerus* in terms of Davidson's choice in 1853 of *P. knightii* J. Sow. as genoelectotype, on the grounds that

With such a change of generic name there would have to be parallel changes in the designation of Family, Superfamily, and Suborder (under Article 5 of the International Rules), a course likely to "result in greater confusion than uniformity".¹

The genus *Pentamerus* with type *P. laevis* J. Sowerby 1813 (after Hall and Clarke's choice, 1894) is accordingly retained in the present paper, and it is intended to submit a case for the retention of this name to the International Commission on Nomenclature.

Family *Pentameridae*.

Genus *Pentamerus* J. Sowerby 1813.

Sowerby, J., "Mineral Conchology", Vol. I, p. 73*, Aug. 1813.

Davidson, T., "British Fossil Brachiopoda", *Palaeontogr. Soc. Lond. [Monogr.]* I, 1853, p. 97; III, pt. vii, pp. 142—157 (1867); V, pt. ii, pp. 161—4 (1883).

Hall, J. and Clarke, J. M., *Palaeontology of New York*, VIII, pt. ii, 1894, pp. 236—240.

Schuchert, C. and Cooper, G. A., "Brachiopod Genera of the Suborders Orthoidea and Pentameroidea", *Mem. Peabody Museum nat. Hist. Yale*, IV, pt. i, 1932, pp. 177—9.

Synonym. *Pentastère* Blainville, H. D. de, in "Dictionnaire des Sciences Naturelles", Vol. 32 (Nov. 1824), p. 301.²

Nomina nuda. *Trimurus* Caldwell, F. E. S., in *Abstr. Diss. Univ. Camb.* 1933—4 (1934), p. 56.

Miopentamerus Alexander, F. E. S. (née Caldwell), *Abstr. geol. Soc. Lond.*, no. 1315 (July, 1936), p. 116.

Genotype: *Pentamerus laevis* J. Sowerby, "Mineral Conchology", Vol. I, p. 76*, pl. 28, bottom right-hand figure (1813). The original specimen came from Buildwas, Salop, England.

up to that date the genus *Conchidium* had not received proper definition. [Cf. Alexander (née Caldwell) in *Abstr. geol. Soc. Lond.*, No. 1315, July 1936, pp. 116—7]. This overlooks the importance of Hisinger's paper of 1799. This author has proposed the name *Trimurus* for Pentamerids of the *P. oblongus* type (*Abstr. Diss. Univ. Camb.*, 1933—4 (1934), p. 56). *Trimurus* Caldwell 1934 has the same meaning as the name *Miopentamerus* Alexander (née Caldwell), *op. cit.*, 1936, over which it has priority, while both are nomina nuda under Article 25 c (1—2) of the Rules.

¹ Resolution of the Commission on Zoological Nomenclature, as reprinted in E. T. Schenk and J. H. McMasters 'Procedure in Taxonomy' 1936 p. 38.

² The status of this name is doubtful. De Blainville quotes it as 'Pentastère Sowerby', and it is possibly only a *lapsus calami*. Cf. the form 'Pentamère' in "Nouveau Dictionnaire d'Histoire Naturelle", Tom. XXV, 1817, p. 161.

Generic description: (partly after Schuchert and Cooper, 1932). Large, smooth Pentamerids, shell depressed to ovate, outline quadragonal—pentagonal, often trilobed anteriorly and frequently with a fold on either valve. Hinge-line gently or sharply curved; cardinal extremities rounded. Ventral valve always the higher, often considerably so. Ventral umbo prominent, curved over the dorsal. Shell-substance fibrous.

In the ventral valve, a long spondylium supported on a long and high duplex septum. A rather wide delthyrium, with (in some species at least) a small pseudodeltidium at its apex.

In the dorsal valve, long cardinalia commonly divided into inner-plates, brachial-processes and outer-plates. The cardinalia may be sub-parallel or slightly divergent, and usually arise at right-angles to the valve-wall. Between the outer-plates a very low, median septum may be present. Cardinal-process rudimentary. Dentition simple, the postero-dorsal edges of the spondylium abutting against the outer surfaces of the inner-plates near the posterior end of the dorsal valve.

European species:

Gypidia borealis C. E. Eichwald 1842.

Pentamerus esthonus C. E. Eichwald 1854.

Pentamerus laevis J. Sowerby 1813.

Pentamerus samojedicus A. Keyserling 1846.

[?] *Pentamerus integer* J. Barrande 1847.

Pentamerus schmidtii N. Lebedev 1892 (? synonym of *P. borealis*).

Discussion: The genus *Pentamerus* is exceedingly variable in external shape and size, but that this variation is of little guide even for a discrimination between species, is illustrated by the range in shape of forms all to be included within the type species. The most diagnostic characters are the smooth exterior, the long, high, and often relatively narrow spondylium duplex and the arrangement of the cardinalia. The shape of the spondylium is very different from that in *Stricklandia* or *Clorinda*. In these two genera the spondylium is fairly wide relative to its length; in *Pentamerus* the spondylium is not only long compared with the whole shell, but very long also in proportion to its width (in early Pentamerids about three times as long as wide, in late species the proportion is much greater). The cardinalia serve to distinguish *Pentamerus sensu stricto* from *Pentameroides* Schuchert and Cooper 1931, here regarded as a sub-genus. The disposition of the secondary thickening and the

presence in some forms of a small pseudodeltidium is extremely interesting and is discussed in detail under the separate species.

The affinities of *P. integer* Barrande 1847, 464, Taf. xxii, fig. 7, are uncertain. This species may be referable to *Pentamerus* s. s., to judge from Barrande's figures, but if so, it extends the range of the genus up to the Downtonian (Barrande's horizon F).

Pentamerus borealis (C. E. Eichwald) 1842.

Plates I and V, figs. 1—4; Text-figs. 2, i—iv, vi, and 3.

1842. *Gypidia borealis* Eichwald, C. E., "Die Urwelt Russlands", II, pp. 74—5, Tab. I, fig. 14. [Advance copy, from *Beitr. Kenntn. Russ. Reiches*, VIII, 1843].

1860. *Pentamerus borealis* Eichwald, C. E., "Lethaea Rossica", vol. I, p. 787.

1892. [?] *Pentamerus schmidtii* Lebedev, N., "Obersilurische Fauna des Timan," *Mémoires du Comité Géologique*, vol. XII, No. 2, pp. 22, 42, Taf. ii, figs. 9 a—c, 10.

1908. *Pentamerus borealis* Eichwald, C. E., Kiær, J., "Das Obersilur im Kristianiagebiete", *Vidensk. Selsk. Skrifter, Math.-Naturv. Kl.* (1906), II, *passim*.

Material: P. M. O., specimens 21 605—09, 40 250—52, 40 410, 40 471—76, 44 821, —24, —27, —41, —99, 44 900, —02, 52 809—22, 53 482—85, 58 418—27, 58 445—72, 58 478—58 520, 58 550—54. (Kiær Collection), from southern Norway.

S. M. C., specimens A. 13 525—36, from Esthonia.

Types: The specimens figured by Eichwald, 1842, Tab. i, fig. 14 (according to Teichert 1928, p. 60, these are no longer existent).

Introduction: Eichwald's original description gives a brief account of the external characters of this species. He considered that it was closely related to '*Gypidia conchidium*' auctt. [= *C. bilocularis*], and he refers to its mode of occurrence as isolated valves forming shell-banks at various localities on the Silurian outcrop in Esthonia. His figure shows specimens with a well developed septum in the ventral valve. The species was easily identified and was chosen by Schmidt (1858 and 1881), as the zone fossil for the horizon G 2 (*Borealis*-bank) in his classification of the Esthonian Silurian. It was soon recognized that its distribution extended to southern Norway.

Diagnosis: *Pentamerus* of rather small, average size. Ventral valve moderately convex; dorsal valve flat, or very slightly convex. Umbones low, a little incurved, approximate, the ventral somewhat the higher. Length always greater than the breadth, which is greater than the thickness. In the ventral valve a relatively short and wide

spondylium, supported on a short septum. In the dorsal valve the cardinalia which are about equal in length to the spondylium, are attached at right-angles to the valve-wall except at their extreme anterior end, where they may be free. The species often possesses an extremely thick shell, but this feature is not invariable.

Discussion: In normal adult individuals the breadth is about two-thirds of the length; the maximum breadth is frequently attained about half-way from the posterior to the anterior margin. This, together with the rather sharp, downward slope of the valve-margins from the umbones, tends to produce a sub-oval or rhombic outline (cf. Plate I, figs. 1, 4, 6—7). The hinge-line is short and strongly curved and there are no cardinal angles. The profile is plano-convex, or slightly biconvex; the curved shape of the ventral valve contrasting with the much flattened dorsal valve. The ventral valve is most curved posteriorly, where it is arched forwards to conceal the dorsal umbo. The greatest thickness may be attained in about the same plane as the maximum breadth or rather more posterior. The anterior margin is straight or slightly flexed to the ventral side.

The dorsal umbo is incurved and fits closely below the umbo of the ventral valve, covering a triangular, rather wide delthyrium, a feature that can only be seen when the valves are isolated (Plate V, figs. 3—4). The delthyrial angle is about 60° . On either side of the delthyrium the valve is strongly curved, but there is no real area, demarcated from the rest of the valve-surface.

The valves are always completely smooth, apart from occasional, inconspicuous, concentric growth-lines; frequently there is hardly a trace of a median fold in either valve, but in some rather large specimens the ventral valve is elevated into a broad, gently arched fold, especially towards the anterior.

The articulation is simple, as is usual in the Pentamerids. There are slight projections at the antero-dorsal corners of the delthyrium, where the free edges of the spondylium separate. These projections, which have but slight dorsal extension from the commissure, fit against the margins of the inner-plates just below the umbo of the dorsal valve (text-fig. 3, transfers 42—8); and to allow for this there is a small inward curve of the dorsal valve-wall at those points.

Internal Characters: In the ventral valve there is a typical development of spondylium, supported on a high, duplex septum (Plate V, figs. 3—4). The spondylium is of the 'long' type, in which

the maximum width of the structure is less than half the length, and in this species the proportion of length to breadth varies between $2\frac{1}{2}$ and 3, to 1. The spondylium is comparatively open, its shape is determined posteriorly by the rather wide delthyrium and by the height of the septum. Thus, the dental-plates, which join the valve-wall along the edges of the delthyrium, slope inwards to enclose the spondylial cavity which is roughly triangular in section. The inward slope of the spondylial walls continues to the anterior end of the structure, at the same time the spondylium gradually narrows and becomes less deep (text-fig. 3, transfers 48 to 99); so that the cross-sectional shape remains triangular throughout, with the dimension of width approximately equal to the depth. As seen in profile, the spondylium curves gently antero-dorsally towards the cavity of the dorsal valve (Plate V, fig. 1). It is supported on a septum for less than half its length. The spondylium of *P. borealis* is thus very different in shape and cross-section from the analogous structures in the later species of *Pentamerus* and it resembles much more closely the *Stricklandia* type, than do the later Pentamerid spondylia.

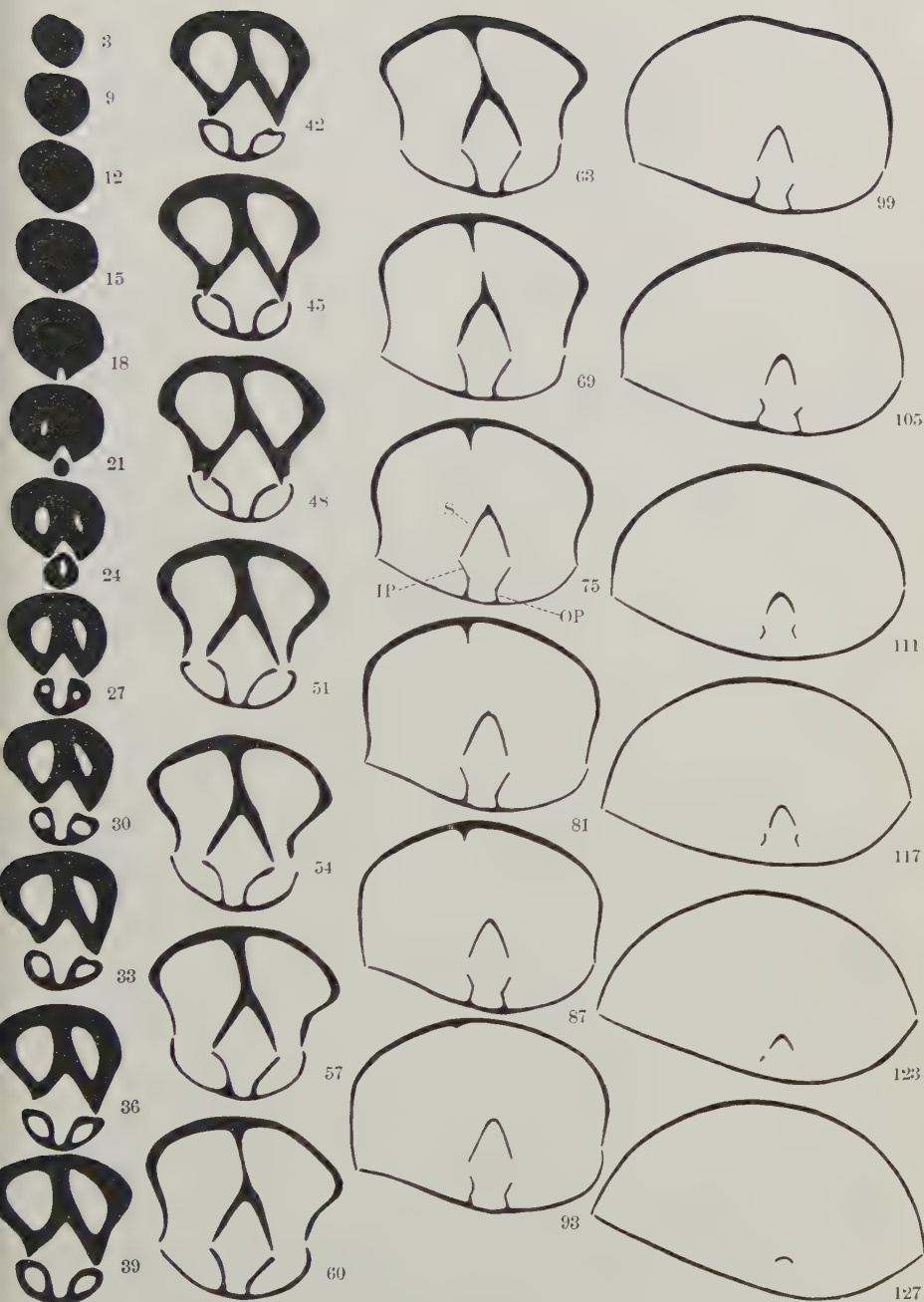
The detailed structure of spondylium and septum may be studied in thin sections and serial transfers (text-figs. 2—3). These show that most of the thickening of the valve-walls is due to an unusually great development of the main shell-layer. There may in addition be an inner layer of secondary shell-material, but this is comparatively thin. The thickness is thus due to continued secretion by the mantle after the early growth-stages. It affects the whole of the posterior region, especially of the ventral valve, including the septum and spondylium, the extent of the thickening gradually diminishing towards the anterior. The thickening is thus different from that present, for example, in *Stricklandia lirata* (forma typica). In that species (St. Joseph, 1935 b, p. 496) it was due to an increase in the amount of supplementary shell-material, while in *P. borealis* it is the primary shell-wall itself, which is thickened. The thickening is so extensive that it may, in advanced forms, fill completely the cavities on either side of the median septum almost to the level at which the spondylial walls separate from the valve-margin.

The development of the internal structures is clearly seen from serial transfers. These reveal the presence of two closely united plates forming a duplex septum, immediately within the outer shell-layer. This septum was thus initiated at a very early growth-stage,

as soon, in fact, as the mantle had secreted the outer shell-layer in the posterior region. The septum is present embedded in the thickened valve-walls, long before it separates as a visible structure supporting the spondylium. It is due to this extension of the septum through the thickened posterior region of the shell that the valve fractures so easily along the median plane.

As may be seen from the serial transfers (text-fig. 3) which form part of a series taken at 0.15 mm intervals, when the septum first appears (transfers 21 to 33) it is thick and short. It gradually thins, and becomes rather higher, elevating the spondylium above the valve-floor: it finally separates in transfer 69, to continue a short distance further as two ridges, one down the centre of the dorsal valve, the other down the back of the spondylium. In normal, adult specimens this separation of the septum occurs about 15 mm from the posterior end of the valve. The duplex character of the septum may be seen from sections and transfers to be very clearly marked throughout its length. The two walls of the spondylium do not fuse at the point at which they meet at the back of the spondylial cavity, but continue as two closely united plates to form the septum. The shell-material composing the greater part of the spondylial walls has a prismatic structure, and is continuous with the material forming the main valve-wall. Lining the whole of the spondylial cavity, however, and extending right to the apex of the delthyrium is another thin layer formed of calcareous lamellae laid down parallel to the spondylial walls (cf. text-fig. 2, I—II, VI). This inner sheath is thickest at the bottom of the spondylial cavity, and may be prolonged a short distance ventrally along the median plane of the septum (text-fig. 2, II); it increases in thickness anteriorly, where it may build the greater part, or even the whole of the spondylial walls (text-fig. 2, III—IV).

The homologies of this inner layer have been discussed in the systematic section, where it is shown that it is of this layer that the pseudodeltidium is formed, when such a structure is present. A pseudodeltidium has never yet been observed in a typical, thick-shelled *P. borealis*; the inward arching of the dorsal umbo covers the delthyrium almost completely, and perhaps obviated the need of this structure. However, in a thin section of a structurally rather more advanced specimen (P. M. O. 53482), from zone 7a Sandvika, Asker, still referable to *P. borealis*, a very thin, deeply concave



Text-fig. 3. *Pentamerus borealis* (Eichwald)

Serial transfers (S.M.C. A. 13502) at 0.15 mm intervals from the posterior end of a specimen; zone 7a, Ringerike. $\times 1\frac{1}{4}$. Transfers 3—127. (Cf. text-fig. 2, I—IV and Pl. V, figs. 1—3.) IP = inner-plates; OP = outer-plates; S = spondylium.

pseudodeltidium may be observed, covering the apex of the delthyrium (text-fig. 2, VI). It is continuous with the inner layer lining the delthyrial cavity. In another specimen (P. M. O. 53485) a small, concave pseudodeltidium may still be seen in place, in the apex of the delthyrium of a ventral valve.

In the dorsal valve the cardinalia commence at a similar early stage. Like the ventral septum, they remain embedded in shell-thickening for some distance below the umbo. They arise at right-angles to the valve-wall and at first remain roughly parallel or are slightly inclined inwards; as soon as they separate as visible structures they divide a median space from two lateral cavities, enclosed between them and the valve-wall (text-fig. 3, transfers 27 to 42). The plates gradually slope outwards (transfers 33 to 42), and finally separate (transfer 45), where they abut against the inner edges of the 'teeth' of the ventral valve. The cardinalia always remain low, and are directed approximately towards the free edges of the spondylium with which they almost come in contact (transfers 45 to 75). The outward inclination tends to decrease anteriorly, while at their anterior end the processes separate from the inner valve-surface and continue free for a short distance (transfers 105 to 127).

The material composing these processes is lamellar in fine structure and resembles that of the thin layer lining the spondylial cavity; it contrasts with the material of the inner shell-layer, which is in contact with the surface of these plates only at the posterior, before their free edges have separated from the valve-wall. Anteriorly (transfers 75 to 117) the plates are seen to have a two-fold division, rather than the tripartite arrangement characteristic of the later *Pentamerus* species.

Remarks: *Pentamerus borealis* is the earliest *Pentamerus* at present recognised and the first member of Kiær's *borealis*-'*oblongus*'-*gotlandicus* morphological series. The gradual lengthening of the septum and spondylium in the ventral valve and of the cardinalia in the dorsal valve, in passing from earlier to later members of this series, has been so often emphasized, that it is well to note that there are other characters in which this species differs from *P. laevis*, and which do indeed justify specific separation. Thus, of the characters that have served in the past to distinguish *P. borealis* from *P. laevis* one of the principal has been the length of the septum, which was considered to be 'short' compared with that in the latter species.

Dimensions of Typical Specimens
(in millimetres).

Length	Breadth	Thickness
53.7	37.9	25.6
50.0	39.4	24.2
45.8	33.4	25.0
74.0	41.4	-
42.0	32.5	-
47.7	38.2	-

Strictly, within each of these two species the length of the septum varies between certain limits, and the ranges would certainly overlap, so that on this feature alone the species merge into one another. Similar arguments apply to the structures in the dorsal valve. The characters which serve to separate *borealis* from *laevis* are rather the relative dimensions of the valves, the outline and profile, and also the shape of the spondylium.

Pentamerus borealis appears to be a relatively stable species, especially when it is compared with *P. laevis*, which shows a far greater range of variation. The characters that are least constant are the curvature of the valves, the development of the fold on the ventral valve, and the outline and profile. The variation is, however, limited; and for example, the form figured by de Verneuil (1845, pp. 119—20, pl. viii, figs. 1a—c) as *P. borealis* is far from being typical of the species, as Teichert (1928) has pointed out. De Verneuil's figures, while agreeing well enough for the profile, show a far too 'pinched in' outline at the posterior, while his description is not wholly applicable.¹ He may have happened to have been dealing with specimens which constituted a variety of the typical *borealis*.

Pentamerus schmidtii Lebedev 1892, would appear, as far as may be judged from Lebedev's description and figures,² either to be very closely related to *P. borealis*, or more probably to be the same form.

Eichwald's original material came from the Silurian of Esthonia (presumably horizon G) at various localities such as Hapsal and Dagö,

¹ Especially the first paragraph on p. 119 (*op. cit.*).

² These show a very thick-shelled form, of *P. borealis* shape and size, with short septum and spondylium [Lebedev, *op. cit.* Taf. ii, figs. 9a—c, 10]. The originals were in the Museum der Akademie, Leningrad.

and an examination of specimens (S. M. C. A. 13 525—36) from this same general region leaves no doubt as to the identity of the material from southern Norway. In the Oslo region, *P. borealis* occurs at horizon 7a of which it is the zone fossil. The horizon is perhaps best studied in the western area at Ringerike and Holmestrand. At Hadeland and Ringerike the development is very characteristic, and it is from the latter district (Limåstangen) that most of Kiær's specimens have come. In a thickness of about 10 m of rock attributed to zone 7a, there are three or four bands varying from 15 to 120 cms in thickness, crowded with the thick shells of *P. borealis*, mostly in the form of isolated valves (cf. Kiær, 1908, pp. 53—6, pls. iii and xxiv). The shells were evidently swept along by currents to form shell-banks, a process in the course of which the valves were nearly always separated. As might be expected from such a method of formation, the area of this development is limited, and nothing quite like it is known in the neighbouring districts. The same conditions prevailed at times, however, in Esthonia, for there too, as was noted by Eichwald (1842, p. 75) *P. borealis* valves build entire shell-banks. At Holmestrand, *P. borealis* is present though it is not nearly so common as at Ringerike, occasional individuals are of the characteristic, thick-shelled form, but the greater number collected by the writer have a much thinner shell, and while still agreeing with the typical *borealis* in shape and type of spondylium, are a little closer to *P. laevis* (cf. Kiær, 1908, pp. 197—201). At Malmøy and Asker, the *P. borealis* development is rather less distinctly characterized (*op. cit.* pp. 152—3, 349 and 488).

The Baltic Provinces and southern Norway are the only areas from which *P. borealis* has been described. In Britain, though it has never been recorded, it is not impossible that a very similar form may be present in some Middle Llandovery horizon.

Pentamerus laevis J. Sowerby 1813.

Plates II, III, figs. 4—6, 10—11; V, figs. 5—6, 10; VI, figs. 16—17;
Text-figs. 2, V, 4—7.

- 1813. *Pentamerus laevis* Sowerby, J., "Mineral Conchology" vol. I, p. 73*, pl. 28.
- 1839. *Pentamerus laevis* J. Sowerby. Sowerby, J. de C., in Murchison's "Silurian System", p. 641, pl. 19, fig. 9.
- 1839. *Pentamerus oblongus* Sowerby, J. de C., *ibid.* p. 641, pl. 19, fig. 10.

1867. *Pentamerus oblongus* J. de C. Sowerby. Davidson, T., "British Fossil Brachiopoda", *Palaeontogr. Soc. Lond. [Monogr.]*, III, pt. vii, pp. 151—5, pls. xviii and xix, figs. 1—2 (with Bibliography). *Idem*, V, pt. ii (1883), pp. 161—2.
1894. *Pentamerus oblongus* J. de C. Sowerby. Hall, J. and Clarke, J. M., *Palaeontology of New York*, VIII, pt. ii, pp. 237 ff., pls. lxxvii—lxx (pars.).
1908. *Pentamerus oblongus* J. de C. Sowerby. Kiær, J., "Das Obersilur im Kristianiagebiete", *Vidensk. Selsk. Skrifter, Math.-Naturv. Kl.* (1906), II, *passim*.
Pentamerus oblongus of the generality of authors.
 [?] Synonym. *Pentamerus beaumonti* Laporte, F. L. de, [=Castelnau, Comte de] *Essai Syst. Silur. Amer. septent.*, 1843, p. 38, pl. 13, figs. 9, 9a.

Material: P. M. O. specimens, 21 280—83, —88—90, 40 408—09, 40 509—16, 42 635—39, —50—53, 42 692—701, 42 788—93, 42 871—72, 42 913—16, 43 002, 43 038—41, 43 189, 43 319—22, —30—53, 43 456—59, —78—83, 43 549—56, —90—92, 43 619—28, —38—45, 53 454—55, —60—66, 53 496—503, 53 521—41, —50—52, 54 684—91, 54 726, 54 834, —58—65, 54 928—33, —44—46, —51—62, 58 555—59, —63. (Kiær Collection), from southern Norway.

Types: The original specimen figured by J. Sowerby (1813, p. 28, bottom, right-hand figure) is apparently lost. Plesiotypes. B. M. (N. H.), BB 125 (figured by J. de C. Sowerby 1839, pl. 19, fig. 9 as *Pentamerus laevis*), from the Silurian of Salop, England.

The history of this species has been fully recorded in the discussion of the synonymy of *Pentamerus* and *Conchidium* (pp. 60—63), and it is there shown that *Pentamerus laevis* J. Sow. 1813 must replace the commonly used name *P. oblongus* J. de C. Sow. 1839.

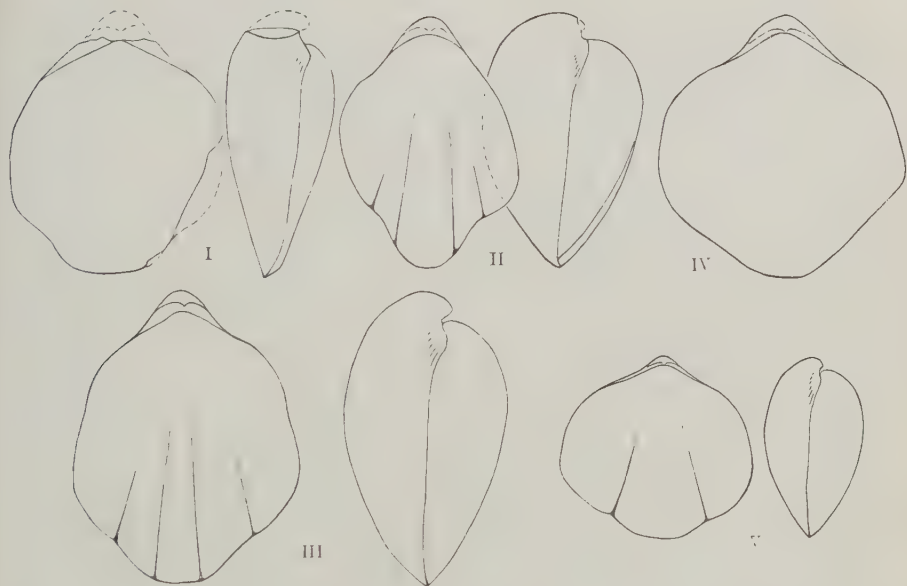
Diagnosis: Large-sized *Pentamerus*, oval, sub-pentagonal or even sub-rounded in outline. Breadth typically two-thirds of the length or rather more, and considerably greater than the thickness. The maximum breadth and thickness are often attained about half-way towards the anterior margin. Hinge-line short, curved. Profile always markedly biconvex, often about equi-convex. Ventral umbo rather high, curved forwards to conceal the dorsal umbo. A low, median fold usually present on both valves. Anterior margin recti-marginate; when the median folds are prominent, the margin may be drawn out into a small, anterior prolongation. Surface often marked by concentric lines of growth. In the ventral valve a triangular delthyrium partially covered by a small pseudodeltidium at

its apex (cf. pl. V, fig. 6). The sides of the delthyrium are supported by dental-plates which unite to form a long, narrow spondylium supported on a high, and relatively long, thin, duplex septum (Pl. V, figs. 6, 10). In the dorsal valve, long and often sub-parallel cardinalia (Pl. V, figs. 5, 10) composed of inner-plates, brachial-processes and outer-plates. Between the anterior portions of the cardinalia a low, median ridge may be present.

Discussion: The variability of *P. laevis* in such external characters as shape, size and profile has often been the subject of comment (cf. Davidson, 1867, pp. 152—3; Hall and Clarke, 1894, p. 237). The typical *P. laevis* is an elongate form, sub-oval in outline, with a biconvex profile, and a low, median fold on each valve. The maximum dimension of breadth thus falls about half-way between the maximum length and the thickness. The hinge-line is short and as in *P. borealis*, the valve-margins usually slope outwards and downwards from the ventral umbo, until the greatest breadth is attained. The characters which the early authors considered most important were the smoothness of the shell, the rounded and often trilobed anterior margin and the incurving of the umbones (cf. J. Sowerby's description 1813, quoted *supra* p. 262, J. de C. Sowerby, 1839 p. 641, Davidson, 1867, p. 152). The great variation from the typical form is due to an accentuation of one more of the external characters. These may be described with reference to the drawings (text-fig. 4; cf. also Plates II and III), which represent the main variants in shape encountered in the Oslo region. The characters which are least constant are the outline and profile, the height of the ventral umbo, and the degree of trilobation of the anterior margin.

The specimens from southern Norway that most closely resemble the typical *P. laevis* (text-fig. 4, I and Pl. VI, figs. 16—17)¹ are perhaps those less trilobate forms from zone 7 b β at Malmøy. Thus P. M. O. 58 563 (cf. text-fig. 4, III) differs only in the slightly greater convexity of the shell and in a tendency towards trilobation. These two features are accentuated in the typical form from this locality and from Holmestrand at the same horizon, which is much more convex and strongly trilobate with a well-developed median fold in

¹ This is interpreted in terms of J. de C. Sowerby's figures in the "Silurian System" (1839, pl. 19, fig 10), and those in Davidson's monograph (1867, pl. xviii and xix). The Norwegian material has been compared with actual, figured specimens.



Text-fig. 4. *Pentamerus laevis* J. Sowerby. (All figures $\times \frac{2}{3}$.)

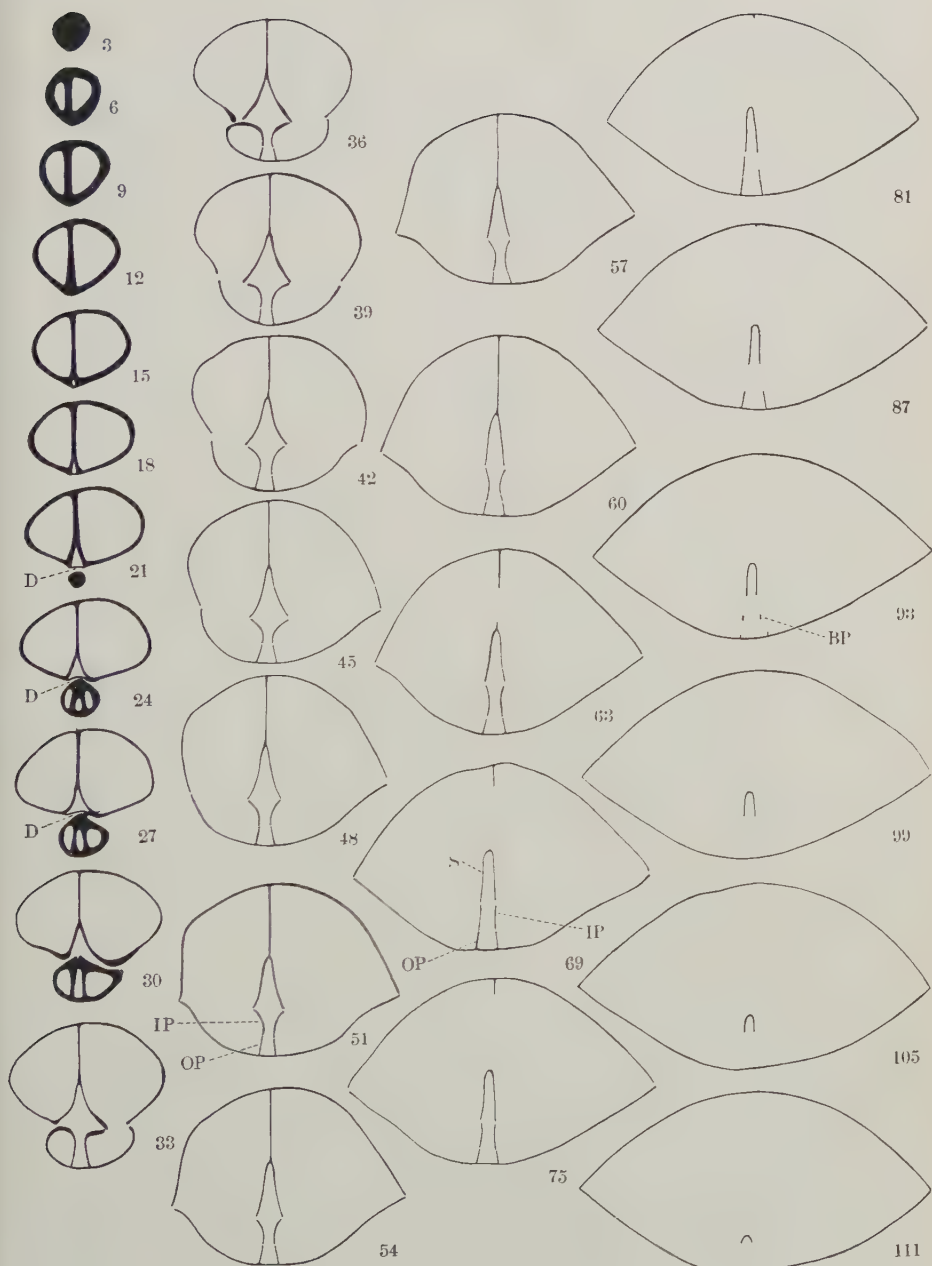
Outline-drawings of the dorsal and right-lateral views of five specimens. I. Geol. Survey Coll., London, 6908 (Plesiotype); II. P. M. O. 58 558; III. P. M. O. 58 563; IV. P. M. O. 54 865; V. P. M. O. 40 520

each valve (P. M. O. specimens 58 555—9, 54 860, 42 789, 43 002 cf. text-fig. 4, II; and Pl. II, figs. 1—3). It is not represented in the collection from any of the other districts. Specimens from Ringerike (zone 7 b) and from Holmestrand in the lower part of this zone differ from the above in being relatively broader and less trilobate (text-fig. 4, IV; P. M. O. 44 910, 54 865). An even more extreme departure from the type is represented by material from 7 a and 7 b α at Malmøy, specimens 43 619—28, 21 280—81, 40 509—10, 40 520, which are less convex, with a rather lower ventral umbo, and broader, with the dimensions of breadth now tending to exceed the length (text-fig. 4, V; Pl. II, figs. 16—18). Individuals from zone 7 a at Sandvika, Asker, 53 521—41, 43 461 are not unlike the foregoing; the dimensions of length and breadth are about the same, the profile is gently biconvex, and there is a tendency to a general subcircular shape with a lengthening of the hinge-line. These specimens occur together with a few individuals (53 455) of about the same convexity but of much more triangular outline.

None of these variations, with the possible exception of the strongly trilobate form of 7 b β , is absolutely restricted to any one horizon. Nor do the extremes stand out distinctly from one another, they are connected by many intermediate types, which occur casually in the series. Text-figure 4 represents of necessity only a few of these shape variations but there are many specimens in the collection which serve to connect the forms that have been selected for drawing. The shape-variations thus merge into one another and have little or no stratigraphical significance; there is no division between the two extremes separating as it were, species from species. In internal characters they show great constancy, a statement that is based on an examination of specimens by serial transfers and thin-sections, specially selected to represent the widest range in external characters (S. M. C. A. 13 503—5, and sections of specimens P. M. O. 53 529—30, 42 914 etc.). These variants then are best regarded as all falling within the limits of the one species *P. laevis*, a conclusion which was evidently reached also by Professor Kiær, for they are so labelled in his collection, while in his monograph he describes them simply as varieties.

The articulation is of the generalized Pentamerid type. At the points where the free edges of the spondylium commence below the antero-dorsal corners of the delthyrium, the spondylial walls are slightly thickened and abut against the outer edges of the inner-plates where they separate at the hinge-line (text-fig. 5). The two points about which articulation takes place are rather closer together than in *P. borealis*.

Internal Characters: The spondylium in *P. laevis* is very constant in character and a feature by which the species may easily be recognized, a single cross-section usually sufficing for determination (text-figs. 5 and 6, Plate V, figs. 6, 10). The structure extends for about half the length of the valves or sometimes a little further. It is a much more advanced example of the 'long' type than that of *P. borealis*, the proportion of length to breadth is thus about 4 or 5, to 1. The spondylium attains its maximum width at the point at which its walls separate from the hinge-line (Pl. V, fig. 6). There, the spondylial cavity is approximately triangular in section (text-fig. 5, transfers 33 to 39), but anteriorly it narrows, the walls becoming nearly parallel and they continue so for the further half of its length (text-figs. 5 and 6, transfers 60 to 105 and 59 to 71 respectively).



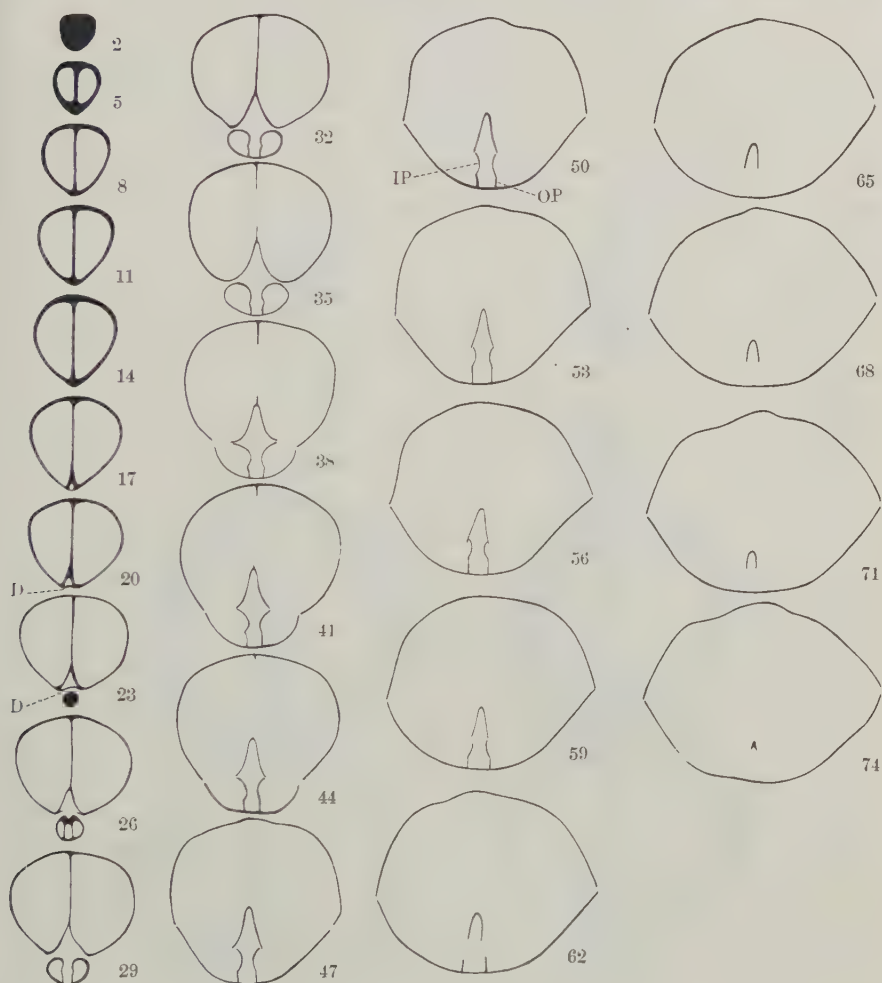
Text-fig. 5. *Pentamerus laevis* J. Sowerby.

Serial transfers (S. M. C. A. 13 503) at 0.15 mm intervals from the posterior end of a specimen; zone 7 b, Malmøy. $\times 1\frac{1}{2}$. Transfers 3—111. (Cf. Pl. V, fig. 10). BP= brachial-processes; D= pseudodeltidium; IP= inner-plates; OP= outer-plates; S.= spondylium.

In its mid-portion the spondylium is thus frequently rather narrow and deep, the ratio of width at its free edges to depth being about 1 to 3. In profile, the front of the spondylium is almost straight, with the back curving gently forward to the cavity of the dorsal valve (Plate V, fig. 10). The structure is usually supported on a septum for about half its length.

The thickening of the valve-walls and internal structures in the posterior region which is commonly present in *P. borealis* hardly ever occurs in *P. laevis*. The shell in this species is usually very thin and the division into two shell-layers is seldom seen. Occasional individuals as, for example, from the lower part of zone 7b at Ringerike show a thickening of the shell towards the posterior, but these may be types intermediate between the two species. The difference may be readily appreciated on comparing text-figs. 3 and 5. The late appearance of the septum as a visible structure in the series of transfers in the former figure, contrasts with its presence in the fourth transfer in the *P. laevis* series. In this species, as in *P. borealis*, the septum is encountered with its typical, duplex character, usually as soon as the outer shell-layer has been removed. It is always thin and relatively high, thus elevating the spondylium considerably above the valve-floor (text-figs. 5, 6), but its height depends to some extent on the convexity of the ventral valve. The duplex nature of the septum is maintained throughout its length, though this may be difficult to observe anteriorly owing to the thinness of the septum and the fine scale of its structure. When viewed in profile as in specimens fractured along the median plane, growth-lines may be seen parallel to its anterior margin.

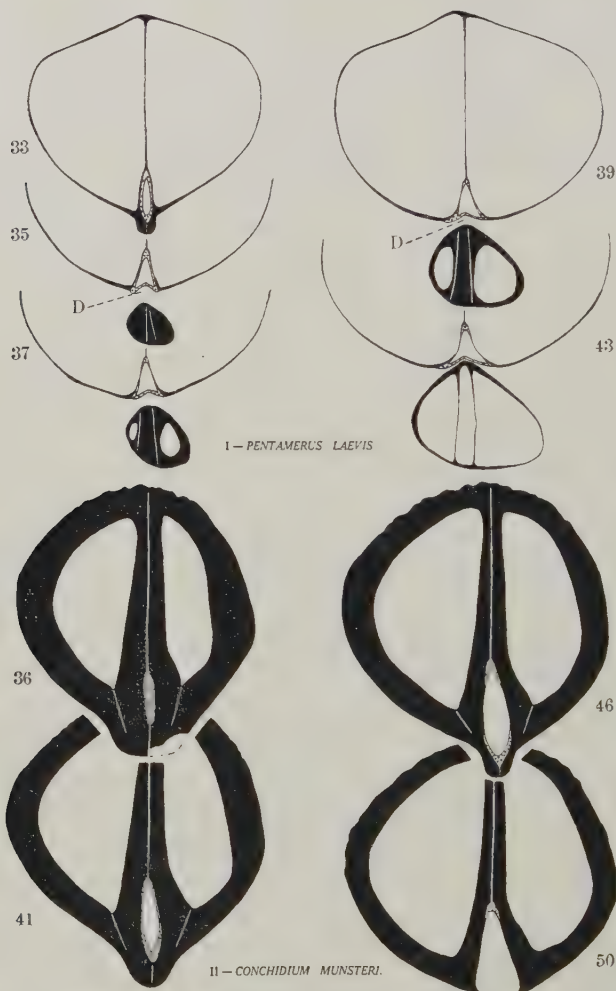
The whole of the interior of the posterior portion of the spondylium is covered by a very thin layer of lamellar material, which evidently corresponds to the similar feature seen in *P. borealis*. The layer is thickest near the umbo, where it may fill the whole of the delthyrial cavity, and along the base of the spondylium. A study of thin-sections and serial-transfers such as those shown in text-figs. 2, V and 7, I, leaves no doubt that the flat or slightly concave covering present at the apex of the delthyrium (cf. text-fig. 5, transfers 18—27) is formed of this same thin layer. This cover over the apex of the delthyrium is of the nature of a pseudodeltidium (Pl. V, fig. 6 and cf. the similar structure in *P. cf. gotlandicus*, fig. 7). In specimens with the two valves in apposition it may be seen to lie very close to the

Text-fig. 6. *Pentamerus laevis* J. Sowerby.

Serial transfers (S. M. C. A. 13 504) at 0.15 mm intervals from the posterior end of a specimen; zone 7b β , Malmøy. $\times 2$. Transfers 2–74. (Cf. Pl. V, figs. 5–6).

D=pseudodeltidium; IP=inner-plates; OP=outer-plates.

incurved umbo of the dorsal valve (cf. text-figs. 5 and 7, I). At the base of the spondylial cavity the thin, covering layer may be prolonged a short distance along the median plane of the duplex septum. Towards the anterior it appears to form the greater part of the spondylial walls, below the point at which the latter separate from the median septum.



Text-fig. 7. I. *Pentamerus laevis* J. Sow. II. *Conchidium münsteri* new species.

I. Serial transfers (S. M. C. A. 13 505) at 0.15 mm intervals from the posterior end of a specimen; zone 7 b β , Bjerkøy, Holmestrand. $\times 2\frac{1}{3}$. Transfers 33—43. D = pseudodeltidium. II. Serial transfers (S. M. C. A. 13 509) at 0.125 mm intervals from the posterior end of a specimen; zone 5 b, Ringerike. $\times 3\frac{1}{2}$. Transfers 36—50. (For the complete series see text-fig. 10.)

The cardinalia in the dorsal valve (Plate V, figs. 5 and 10) are clearly divisible into two pairs of plates, the inner-plates and outer-plates (text-figs. 2, V; 5 and 6). These commence at the dorsal umbo and form a tripartite division of the posterior region of the valve;

Dimensions of Typical Specimens

(in millimetres).

Length		Breadth	Thickness	
	50.0	40.6	21.5 ¹	
	59.4	42.3	34.2	P. M. O. 58 563
	58.4	46.8	39.7	
Trilobate forms	49.4	34.1	30.6	» 58 558
	38.6	34.3	24.2	» 54 859
	41.0	33.4	22.5	» 58 555
	48.2	36.0	33.4	
	51.0	49.4	34.6	» 54 865
Broad variety	32.5	35.4	18.5	» 40 509
	36.4	37.9	20.5	» 40 520
Variety from 7 a at Asker	34.2	33.4	19.9	
	30.7	27.3	15.7	» 53 524
	32.2	33.2	18.0	» 53 536

when they separate as distinct structures, at about the level of the hinge-line, the outer-plates are sub-parallel and arise roughly at right-angles to the valve-wall, while the inner-plates are markedly convex to one another and are directed towards the free edges of the spondylium (text-figs. 5 and 6, transfers 33 to 39, and 35 to 41 respectively; cf. also Pl. V, fig. 10), with which they almost come in contact. Further towards the anterior margin this convexity decreases, and the line of junction of the two pairs of plates becomes less distinct. The outer-plates are frequently continued for a short distance beyond the inner-plates, in contact with the valve-wall (text-fig. 5, transfers 81 to 93). The bases of the brachial-processes appear in these specimens to be fused with the outer-plates, but the presence of a double rather than a treble division (as is typical of the Pentamerids) may be due to the preservation of the material. The brachial-processes themselves may be seen in some specimens (P. M. O. 58 557, 42 653) continuing beyond the inner- and outer-plates (cf. text-fig. 5, transfer 93, and Pl. V, fig. 10).

Remarks: *Pentameris laevis* is by far the commonest and most widely distributed species of this genus in the Oslo region, as also in Britain. It occupies a middle position in Kiær's developmental series, and was considered by him to connect the short septate

¹ Present dimensions of the specimen (Geol. Survey Coll., London, 6908) figured by J. de C. Sowerby in the "Silurian System" 1839, pl. 19, fig. 10 (right-hand figure).

P. borealis with the long septate *P. gotlandicus*. The range of length of septum in *P. laevis* certainly falls between these two species and forms a convenient and useful guide for rough field-determinations. The biconvex profile, the frequent presence of a fold in both valves, the greater height of the ventral umbo, and usually the thinness of the valve-walls are characters which readily serve to distinguish the great majority of specimens of *P. laevis* from *P. borealis*. Detailed study reveals other important differences. A pseudodeltidium is normally present in *P. laevis* while it has never been observed in the typical, thick-shelled *P. borealis*. The spondylium in *P. laevis* is much narrower and deeper than the corresponding structure in *P. borealis*, in the former the spondylial walls are often parallel, in the latter they are always inclined to one another so that a cross-section of the spondylial cavity approximates to an equilateral triangle (cf. text-figs. 5 and 3). In the dorsal valve, the cardinalia have the same general form in the two species, but in *P. laevis* each process appears to consist of three plates which are fused along their edges, in *P. borealis* this multiple structure has not been observed.

The great range in shape and size exhibited by *P. laevis* has already been discussed (pp. 85—7), and it has been remarked that it is the constancy of the internal characters which indicates that all these variations should be included within the same species. A point of special interest is the relation between *P. laevis* and allied species of *Pentamerus* occurring at the same horizon. Thus, the existence of *P. samojedicus* Keyserling which closely resembles some shape-variations of *P. laevis* in external form while it differs internally, justifies the grouping of the *P. laevis* varieties under one species, quite as much as does the latter's constancy in internal characters. *P. samojedicus* differs according to Keyserling (1846, p. 236) from *P. laevis* in the greater thickness of the shell, in the possession of a relatively short septum and in the form of the spondylium. His figures (*Ibid.*, tab. 9, figs. 2 a—b) show a form with a rather short, but high, septum and wide spondylium, in shape somewhat resembling that of *P. borealis*, and in the dorsal valve short cardinalia. This is, clearly, a short-septate form of *borealis* type, but in proportions and outline much closer to *P. laevis*¹. Keyserling's

¹ Another point of resemblance to *P. laevis* is the prominence of the small median septum in the dorsal valve (cf. Keyserling *ibid.*, Tab. 9, fig. 2. f.).

specimens came from the Silurian limestones of northern Russia (Petschora) but are assignable to no precise horizon.

Pentamerus esthonus, to judge from Eichwald's description (1854, pp. 91—3; 1860, pp. 789—91) and from specimens in the British Museum (Natural History), London (B. 20, BB. 159—60), differs from *P. laevis* in its much larger average size, a feature which in itself might hardly justify specific separation, but this is combined, in the specimens that the writer has seen, with the presence of a curved cardinal-area in the ventral valve on either side of the wide delthyrium and apparently a much higher spondylium, but the internal structures have not been fully investigated. The form may be only a rather distinct variety of *P. laevis*.

In southern Norway, the beds with *P. laevis* comprise the zone 7 b, an horizon that is particularly well developed in the Ringerike, Holmestrand, Malmøy and Asker districts, and it is these areas that have yielded most of the specimens in the collection. At Ringerike a thickness of about 25 m was assigned by Kiær to 7 b, while at Malmøy this division is rather thicker (35 m). In the last locality two sub-zones are recognizable, 7 b α characterized by a broad and moderately short variety of *P. laevis* (Kiær, 1908, p. 489), and 7 b β with a large, strongly trilobate form, cf. text-fig. 4, II, and Plate II, figs. 1—3 (Kiær, *ibid.*), which apparently occurs also in the Holmestrand area (at Bjerkøy), high up in 7 b (Kiær, *ibid.* p. 203.) At Asker (Sandvika) in 7 a—b there is an entirely different shape variation, a thinner and relatively broad form with a depressed ventral umbo (cf. text-fig. 4, V), but with internal structures identical with those of the typical *P. laevis* (cf. thin-sections of specimens P. M. O. 53 529—30 (text-fig. 2, V) and transfer series S. M. C. A. 13506). Most of these variations in external shape (Pls. II and III) appear to be entirely random in space as between district and district, and in time from one horizon to another; they thus have no real stratigraphical value. British material shows an analogous variation in external characters, again seemingly without stratigraphical significance, while to judge from published figures of specimens from the Baltic Provinces and from America, similar, great ranges of variation occur there also.

Sub-genus *Pentameroides* C. Schuchert and
G. A. Cooper 1931.

- Schuchert, C. and Cooper, G. A., *Amer. J. Sci.*, (5), vol. 22, 1931, p. 248.
 Schuchert, C. and Cooper, G. A., "Brachiopod Genera of the Suborders Orthoidea and Pentameroidea", *Mem. Peabody Museum nat. Hist. Yale*, IV, pt. i, 1932, p. 179.
 Genoholotype: *Pentamerus subrectus* Hall and Clarke, *Palaeontology of New York*, VIII, pt. ii, 1894, p. 238, pl. lxix, figs. 2—3, 8—10. The figured specimens came from the Niagara group of Iowa, U. S. A.

Schuchert and Cooper proposed in 1931 a new genus *Pentameroides* for specimens which externally are similar to *Pentamerus* but differ internally in the dorsal valve in that the cardinalia are united to form a sessile, or partly, or wholly, elevated cruralium. When studying internal casts such specimens can readily be distinguished from *Pentamerus s. s.* since they show a single median furrow in the dorsal valve, instead of the two in the latter genus.

The distance between the crural-plates in different species of *Pentamerus s. s.* is somewhat variable, and in the later forms in southern Norway (towards the top of zone 7 b), they may be close to one another, though never in contact. They unite, however, to form a sessile, or partly elevated cruralium in '*Pentamerus*' cf. *gotlandicus*, a species which Kiær considered to have descended from *P. laevis*. It would seem that *Pentamerus* gradually merges into *Pentameroides* through the approximation and final union of the cardinalia and until the limits of the latter form are more closely defined, the writer would prefer to regard it as a sub-genus.

Pentamerus (*Pentameroides*) cf. *gotlandicus* N. Lebedev 1892.

Plates V, figs. 7—8; VI, figs. 13, 15; text-figs. 1 and 8.

1892. *Pentamerus gotlandicus* Lebedev, N., "Obersilurische Fauna des Timan", *Mém. Com. géol. St.-Pétersb.*, vol. XII, No. 2, pp. 22, 42, Taf. II, figs. 11 a—b, 12.
 1908. *Pentamerus gotlandicus* Leb. Kiær, J., "Das Obersilur im Kristianiagebiete", *Vidensk.-Selsk. Skrifter, Math.-Naturv. Kl.* (1906), II, pp. 66, 271—3, 356, 494, 500 etc.
 1925. *Pentamerus gotlandicus* Leb. Munthe H., et alii. "Gotlands Geologi", *Sverig. geol. Unders. Afh.*, Ser. C, No. 331 (Årsbok 18: 1924), p. 19.

Material: P. M. O., specimens 21 675—79, 40 477—81, 45 380—81, 45 423—24, —66—67, —78, —80—81, —93—96, 58 560—62.
S. M. C., specimens A. 6755—58.

Types: The specimens figured by Lebedev 1892 (Taf. II, figs. 11 a—b, 12). Of these, the originals of figs. 11 a—b were stated by him to be in the Museum der Akademie, of fig. 12 in the Museum des Berginstituts (Leningrad).

The original specimens came from Gotland; they are large forms, 8—10 cms long, with a high, ventral umbo and low, broad, median, ventral fold. The septum in the ventral valve apparently extended for more than half the length of the shell. The Norwegian examples were referred by Kiær to Lebedev's species and are here so described pending a re-examination of the Gotland material.

Diagnosis: Large-sized *Pentamerus*, generally subtriangular in outline. Breadth less than the length and considerably greater than the thickness. The maximum breadth is attained near the anterior margin. Profile gently biconvex. Ventral umbo moderately high; often a low, median fold in the ventral valve. A wide delthyrium, covered at its apex by a pseudodeltidium (see Pl. V, fig. 7). A long spondylium duplex, with a high, supporting septum, which in adult individuals extends at least for one-half of the length of the valve. Spondylial cavity posteriorly often Y-shaped in cross-section, anteriorly extremely narrow and with parallel walls. In the dorsal valve, high and very long cardinalia which meet to form a cruralium (Pl. V, fig. 8); this is sessile posteriorly, while anteriorly it is slightly elevated on a median septum, formed by the union of the outer-plates.

Discussion: There is insufficient material to permit of a full account of the variation in external characters, especially as most of the specimens occur as isolated valves. The species is more triangular in outline than *P. laevis*, the greatest width being attained close to the anterior margin (Pl. VI, fig. 15), but large specimens may be of an oval shape. In profile, the convexity is about the same in the two species (cf. Pl. VI, fig. 13 with fig. 16), strongly convex forms have not been seen. The median fold on the ventral valve is a late growth-feature, being most marked in the largest specimens; it may produce a slight extension at the anterior margin. There is a tendency in some individuals (P. M. O. 58 562) to form a small cardinal-area in the ventral valve, but this is not very sharply separated from the rest of the valve-surface. The dorsal valve fits

closely below the umbo of the ventral valve, almost touching the strongly concave pseudodeltidium. In the one specimen in which it has been measured, the delthyrial angle is about 70° . The anterodorsal corners of the delthyrium are not thickened to serve as teeth, nor do there appear to be any other articulatory processes. The maximum possible movement about the hinge-line is very small, owing to the close approximation of the umbones.

Internal Characters: The internal characters readily identify this species among all other European Pentamerids. It is a thin-shelled form, while the changes in the spondylium and cardinalia that are apparent when a typical *P. borealis* is compared with *P. laevis*, reach a further expression in *P. cf. gotlandicus*. The spondylium is extremely long (Pl. V, fig. 7); in the few specimens of which the interior has been examined, it extends for about two-thirds of the length of the shell. The supporting septum which is thin and high (text-fig. 8), is typically duplex throughout its length. Its line of junction with the valve-wall may be traced on the exterior of specimens, from the ventral umbo usually for about two-thirds of the distance to the anterior margin. The septum itself divides above this level and continues as two ridges, one down the back of the spondylium, the other down the inner surface of the valve.

The shape of the spondylium may be seen from text-figure 8 and Plate V, fig. 7. It is at the anterior end of the delthyrium that the spondylial cavity attains its maximum breadth, a dimension that is about one-fifth of its length. There, the ventral part of the cavity is narrow, but dorsally the spondylial walls bend sharply outwards to conform to the edges of the delthyrium (cf. text-fig. 8, transfers 38 to 55). When the free edges of the spondylium separate at the hinge-line they gradually approach each other so that the spondylial cavity becomes narrow and parallel-sided, conditions which are maintained for the rest of its length (transfers 77 to 143). In lateral view, the dorsal edges of the spondylium appear almost straight, while the back of the spondylial cavity curves gradually forward towards the anterior part of the dorsal valve.

The detailed structure of the spondylium and septum is very well preserved in the specimens that have been sectioned, the divisions between the different shell-layers being usually more distinct than in the two previous species. The greater part of the septum and spondylium is composed of shell-material which appears to be similar

to that of the valve-wall, and it is continuous with the latter along the base of the septum. The additional, thin layer that is present in *P. borealis* and *P. laevis* is especially clear in this species (text-fig. 1, where the stippled portions indicate the layer in question). It is thickest at the back of the spondylial cavity in the posterior region, and may extend towards the valve-wall as a continuous selvage along the median plane of the duplex septum. This layer lines the whole of the delthyrial cavity, and is slightly thickened along the sides of the delthyrium. Below the apex the two sides join to form a deeply concave and rather large pseudodeltidium (text-figs. 1 and 8, transfers 18 to 30; Pl. V, fig. 7); this is demarcated by a slight furrow from the surface of the valve on either side. When the valves are in apposition, the dorsal umbo presses closely into the concavity of the pseudodeltidium (text-fig. 1, transfers 26 to 30), allowing no room for the passage of a pedicle. Towards the anterior end of the spondylium, the structure is less clear, but the inner layer appears to be present throughout and to form a thin lining to the spondylial cavity (text-fig. 1, transfer 40).

In the dorsal valve, the form of the cardinalia is very characteristic. These compose a thin-walled cruralium which is sessile posteriorly, and in some individuals for the greater part of its length, but slightly elevated anteriorly (text-fig. 8, transfers 39—143; Pl. V, fig. 8). The cruralium is closely similar in shape and size to the spondylium and its margins correspond roughly to the free edges of the latter (text-fig. 8). The structure of the cruralium is readily seen from thin-sections and transfers. It consists of three pairs of plates, inner-plates, brachial-processes and outer-plates (text-fig. 8, transfers 59 and 65), the latter unite and together with some adventitious shell-material, form the supporting septum. The structure is thus the same as that described by Schuchert and Cooper (1932, p. 164, fig. 27) as typical of *Pentameroides*. Posteriorly, the inner-plates, which are very thin throughout, are strongly convex to one another, while anteriorly they become almost parallel (Pl. V, fig. 8). Their lines of junction with the bases of the brachial-processes may be marked by a very slight flexure in the walls of the cruralium (text-fig. 8, transfer 59). The bases of the brachial-processes are similarly convex posteriorly and sub-parallel anteriorly. The sides of the cruralium change direction along the junctions of brachial-processes and outer-plates, the latter sloping sharply inwards to unite just above the

Dimensions of Typical Specimens
(in millimetres).

Length	Breadth	Thickness
45.5	37.4	19.1 (young specimen)
65.0	60.0	-
55.0	52.0	-
70.0	61.0	-

valve-floor (text-fig. 8). The development of the cardinalia may be traced in the earliest sections immediately below the dorsal umbo. The three-fold division is there maintained, while even as soon as they are visible embedded in the thickening of the valve-wall, the outer-plates unite just within the exterior surface of the valve (text-fig. 1, transfers 26—30).

Remarks: *Pentamerus* cf. *gotlandicus* is the latest species of *Pentamerus* to occur in southern Norway, and the end member of the morphological series traced out by Kiær in the smooth Pentamerids. It may easily be distinguished from *P. laevis*; the shape and usual large size of the valves, the long septum, spondylium and cardinalia are useful guides for rough determinations; in thin-sections, the deep and very narrow spondylial cavity and especially the presence of a cruralium are diagnostic characters (cf. text-fig. 8 with figs. 5 and 6). The pseudodeltidium appears generally to be larger than in *P. laevis*, but agrees closely in structure with that observed in a specimen of *P. cf. esthonus* in the British Museum, London (B. 50).

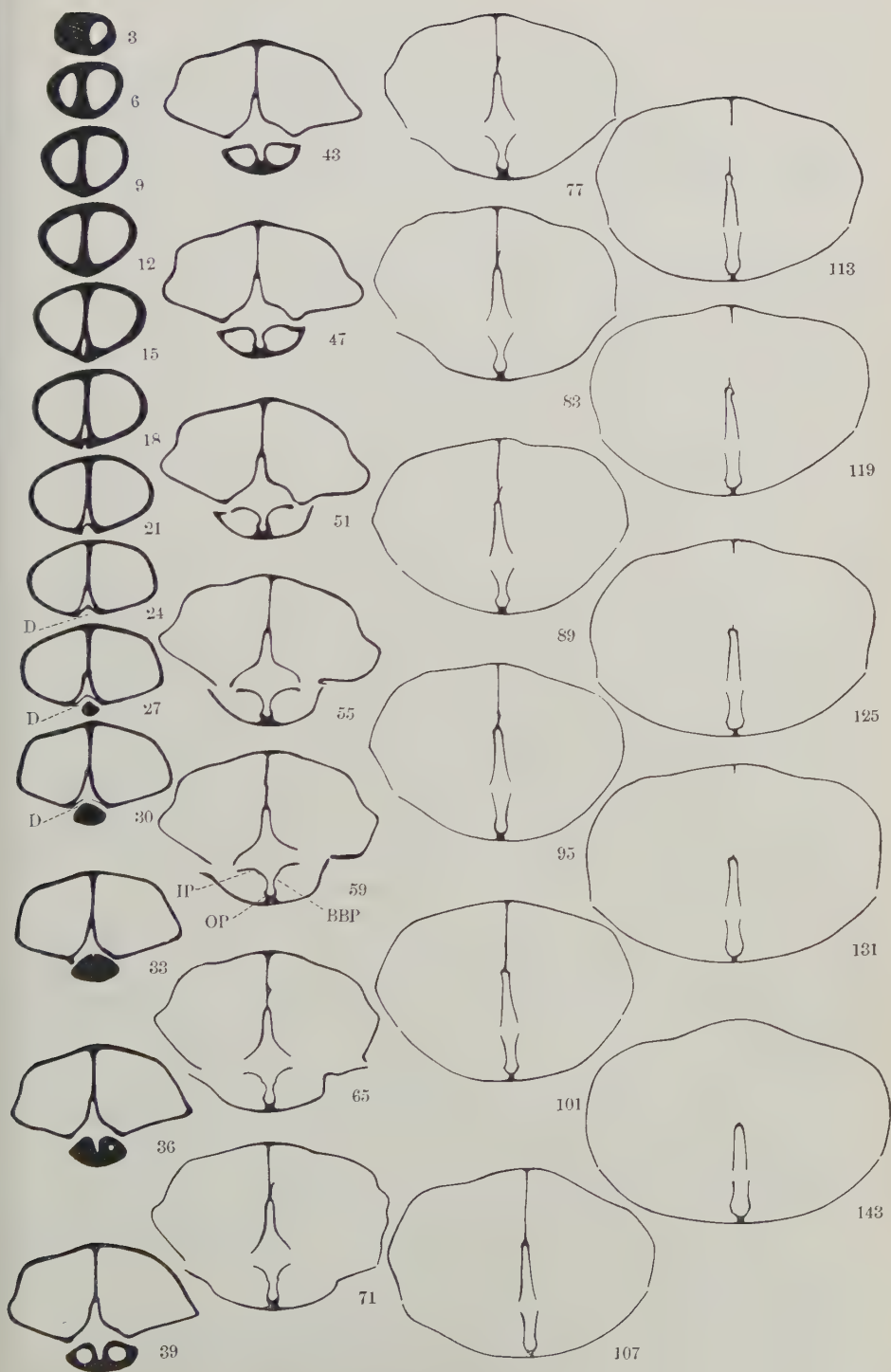
In southern Norway, *P. gotlandicus* was chosen by Kiær as a zone fossil for 7c. It is common in the western development at Ringerike where it occurs with *S. lirata* in 7c β , while Kiær records (1908, pp. 271—3) large individuals, that had been distorted by pressure, from horizons 7c α — γ at Skien and Porsgrund. The species is present also at Holmestrand in 7c β , again associated with *S. lirata* (Kiær, *op. cit.*, p. 207). In the eastern development, as at Malmøy and

Text-fig. 8. *Pentamerus* (*Pentameroides*) cf. *gotlandicus* Lebedev.

Serial transfers (S. M. C. A. 13507) at 0.15 mm intervals from the posterior end of a specimen; zone 7c β , Ringerike. Natural size. Transfers 3—143.

(Cf. text-fig. 1 and Pl. V, figs. 7—8.)

BBP = bases of the brachial-processes; D = pseudodeltidium. IP = inner-plates;
OP = outer-plates.



Text-fig. 8.

Asker it is hardly ever found, at the latter locality *P. laevis* appears to persist (in horizons 7 b β —c γ) rather later than in the other districts.

In Gotland, the type area for *P. gotlandicus*, it has been recorded recently (Munthe, 1925, p. 19) from the Slite group — it thus continues there rather later than *S. lirata*, its common associate. It does not appear to be known from Britain; in America species such as *P. subrectus* are generally similar in internal structure.

Genus *Holorhynchus* J. Kiær 1901.

Kiær, J., "Etage 5 i Asker ved Kristiania", *Norg. geol. Unders.* [Aarbog for 1902], No. 1, 1901, pp. 68—77, figs. 1—7 and pp. 103—9 (English trans.).

Schuchert, C. and Cooper, G. A., "Brachiopod Genera of the Suborders Orthoidea and Pentameroidea", *Mem. Peabody Museum. nat. Hist. Yale*, IV, pt. i, 1932, p. 180, pl. 27, fig. 20.

Genoholotype: *Holorhynchus giganteus* J. Kiær 1901, *op. cit. supra*.

This genus was proposed by Kiær, to include large specimens from the Lower Silurian of southern Norway, which are not unlike a transverse *Pentamerus*, but which differ internally in the possession of a free spondylium in the ventral valve. In the dorsal valve the cardinalia are of a generalized type, and free for almost their entire length.¹ Kiær's original description is quite detailed, and it is not proposed to give here a revised generic diagnosis, the new facts that have been learnt concerning the internal structures are presented under a discussion of the one species that is yet known.

Holorhynchus giganteus J. Kiær 1901.

Plate IV; Text-fig. 9.

1901. *Holorhynchus giganteus* Kiær, J., "Etage 5 i Asker ved Kristiania", *Norg. geol. Unders.* [Aarbog for 1902], No. 1, 1901, pp. 68—74, figs. 1—7.

1933. *Holorhynchus* cf. *giganteus* Kiær. Kulling, O., "Bergbyggnaden inom Björkvattnet—Virisen-området i Västerbottensfjällens centrala del", *Geol. Fören. Stockh. Förh.*, Bd. 55, pp. 242—3, Tav. 10, figs. 1—5.

Material: P. M. O., specimens 12 393—94, 12 402—05, —08—09, —11, 12 428—31, —34—37, 12 452, —57, 12 462, —66—67, 12 488—91, 12 505, 16 656, —58, —82, 20 823—24, 58 604, 60 021 (mostly fragmentary), from southern Norway.

¹ Not attached to the valve-floor, as Kiær thought (*op. cit.*, p. 72).

B. M. (N. H.). London, B 4214, B 4223—24, BB 143—46, (Kjerulf Collection), from southern Norway.

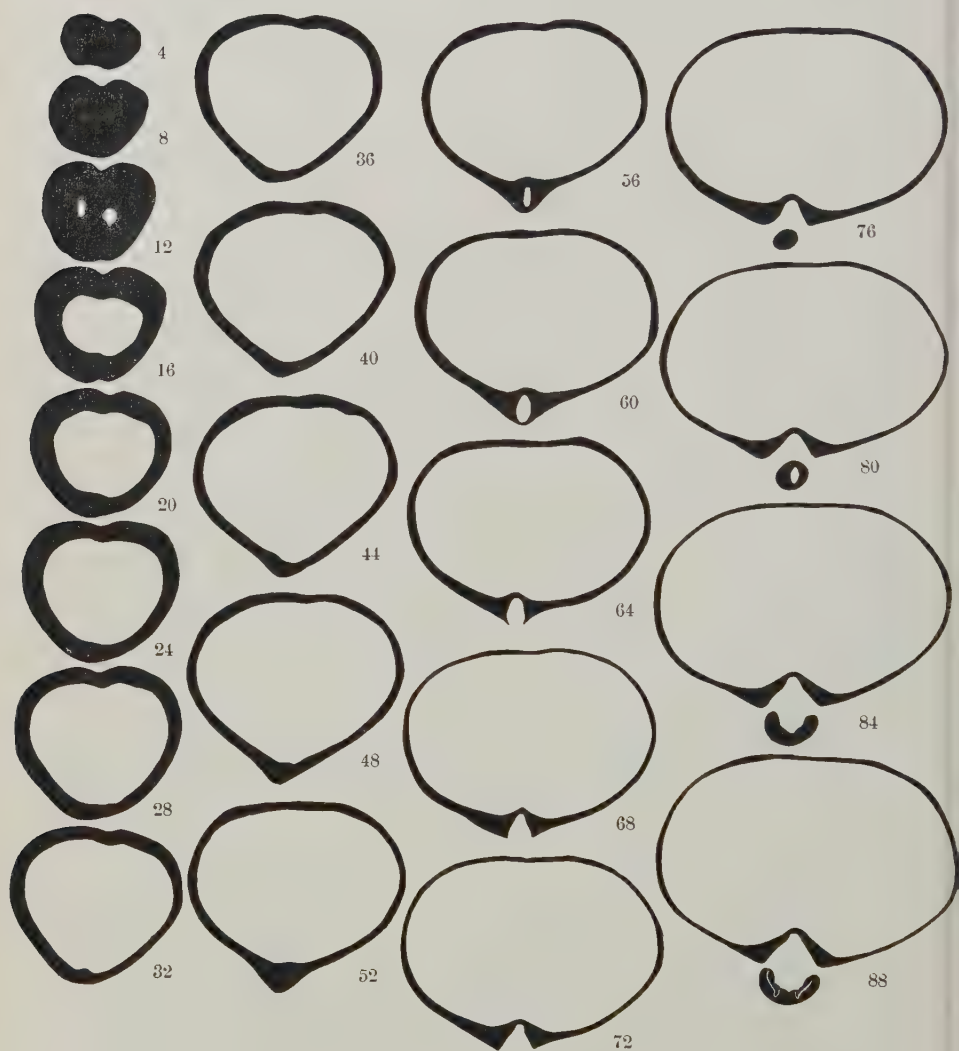
Lectotype (chosen by Dr. T. Strand in MS.): P. M. O., 12431, figured Kiær, *op. cit.*, pp. 70—71, figs. 1—3, Horizon 5 b, from Aspelund, Asker, Norway.

Kiær's original account was based on specimens mainly from the Kjerulf Collection that came from Asker and Ringerike, the only two districts in Southern Norway in which the species is known to occur. The material is preserved partly in the form of casts, partly with the shell still present, while not more than twelve specimens are reasonably complete.¹

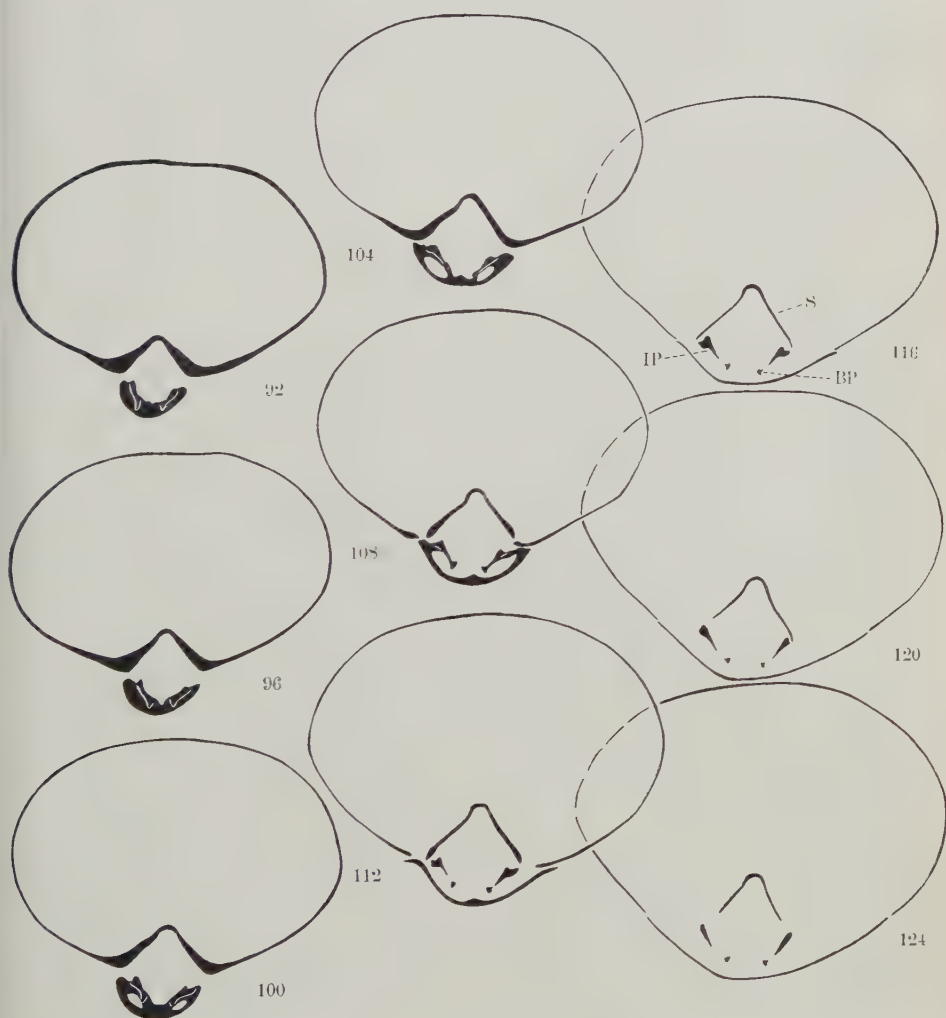
Diagnosis: Largely as for the genus. Outline subcircular: the breadth is rather greater than the length and about twice the maximum thickness. Profile biconvex. Ventral valve the higher, the umbo always well developed (Plate IV). Dorsal umbo low, carried forward beneath the ventral umbo, largely concealing the triangular delthyrium. Hinge-line short, nearly straight. In the ventral valve a rather large, free spondylium; the spondylial cavity is triangular in cross-section. In the dorsal valve long, slender brachial-processes which are free for the greater part of their length, also a second pair of plates inclined outwards from the processes towards the edges of the spondylium.

Discussion: This species was regarded by earlier authors as a large, transverse *Pentamerus* (Kjerulf, 1857, pp. 86 and 95; and 1865, p. 18), to which genus it shows a general, though superficial resemblance. Most of the specimens are of large size; the maximum breadth, which is attained about half-way from the posterior to the anterior border, usually exceeds the length. The edges of the valves curve round approximately as semicircles from the hinge-line to the anterior margin (Plate IV, figs. 1, 4). In profile, the ventral valve is generally more convex than the dorsal (Plate IV, figs. 2, 3, 5). Kiær described a narrow area occurring on each side of the delthyrium, and separated from the rest of the valve-surface by a small, raised line (1901, pp. 69, 72 and fig. 5). This feature is doubtfully present on the lectotype, but does not seem to occur of any of the other specimens.

¹ In view of the relative scarcity of the material one specimen only has been submitted to serial sectioning.

Text-fig. 9. *Holorhynchus*

Serial transfers (S. M. C. A. 13508) at 0.15 mm
 zone 5 b, Asker. Natural size. Transfers
 IP = inner-plates;



giganteus Kiær.

intervals from the posterior end of a specimen:

1—124. BP = brachial-processes;

S = spondylium.

The surface of the valves is smooth apart from occasional, slight, radiating furrows. In the ventral valve, a median furrow commencing just below the umbo is almost invariably present and frequently there is a furrow on either side. The development in the dorsal valve is generally similar. Concentric growth-lines may be prominent especially towards the anterior margin. Articulation is on the usual Pentamerid plan. The free edges of the spondylium just below the delthyrium approach the inner pair of plates in the dorsal valve, where these separate at the hinge-line (text-fig. 9, transfers 104—112).

Internal Characters: The spondylium in the ventral valve is free throughout its length (text-fig. 9, transfers 56 to 124), and there is no trace of a median septum in any of the specimens that have been examined.¹ The spondylium is thus only attached to the valve-wall along the sides of the delthyrium. A longitudinal furrow may be observed in some specimens (P. M. O. 16658) crossing the spondylial walls just below the delthyrium. This was observed by Kiær (1901, p. 72) who considered it to separate the growth-tracks of the antero-dorsal corners of the delthyrium, which functioned as 'teeth', from the rest of the spondylial walls. The latter are usually thin; they enclose a cavity which is approximately triangular in cross-section. Towards the anterior the spondylial cavity becomes less deep (transfers 150 to 170; not figured) and the walls tend to be more parallel, while the whole structure curves forward towards the dorsal valve. The thin layer lining the spondylial cavity that is present in *Pentamerus*, appears also to occur in *Holorhynchus*, though the structure is usually not so clear, and the layer is less sharply separated from the rest of the shell-material. A pseudodeltidium has never been observed, the sides of the delthyrium converging just below the umbo (text-fig. 9, transfers 60 to 64). The spondylium retains no trace of a duplex character, for the walls unite at the back of the spondylial cavity, without any indication of a median suture.

In the dorsal valve the cardinalia consist of two pairs of plates (text-fig. 9, transfers 104—124); a central pair in the form of long, slender rods, which constitute the brachial-processes (= 'crura'), and

¹ Text-fig. 9, transfer 12, does not represent a rudimentary median septum, but rather the slight infolding of the valve-wall, corresponding to the shallow, external furrow.

a second pair which posteriorly are in contact with the brachial-processes and which are directed towards the free edges of the spondylium. It is proposed to call this second pair of plates the inner-plates, without regard to their function. The development of the brachial-processes and inner-plates may be traced just below the dorsal umbo, where these structures are embedded in supplementary thickening (text-fig. 9, transfers 88 to 100). Two small cavities are present posteriorly between the inner-plates and the valve-wall (transfers 100 to 104); the brachial-processes and inner-plates then separate from the valve-wall (transfers 108 to 112) and continue anteriorly as free structures. They may at the same time separate from one another (transfer 112), or continue for a short distance in contact. The brachial-processes consist of flattened rods inclined inwards, and having a small projection towards the inner-plates. They continue as far anteriorly as the end of the spondylium,¹ a distance of some 15 mm from the dorsal umbo, while they diverge slightly from one another.² The inner plates maintain an approximately constant inclination to each other, of rather less than a right-angle. Anteriorly, they decrease in size and in the specimen that has been sectioned, they extend to only half the length of the brachial-processes.

The shell of *H. giganteus* is frequently very thick in the posterior region (text-fig. 9, transfers 1 to 32); near the ventral umbo it may attain as much as 6 mm in thickness, while it gradually thins away towards the anterior. The shell-material is seen from transfers to be coarsely prismatic in structure. The whole of the interior of the posterior portion of the shell, particularly of the ventral valve is covered with irregular pits or depressions. This feature may extend as far as half-way towards the anterior margin; it causes a very characteristic roughened surface on internal casts (specimens P. M. O. 12393, 12457; B. M. (N. H.) BB 124—5). Anteriorly, the rugosities often join together to form small, irregular ridges. The pits are of the same character as those formed by the ligamentous ties, which fix the genital glands to the valve-wall, in living brachiopods. In the

¹ In the series of transfers represented in text-fig. 9, the brachial-processes continue as far as transfer 170, the inner-plates as far as transfer 134.

² The "sloping, rising, longitudinal rib" mentioned by Kiær (1901, pp. 72, 106) as occurring on the "crural plates", is formed by the slight extension of the brachial-processes from the plane of the inner-plates towards the centre of the valve.

Dimensions of Typical Specimens
(in millimetres).

Length	Breadth	Thickness
66.5	75.0	38.6 (Lectotype).
64.5	66.2	34.8
62.2	70.3	40.5
66.0	74.0	-
78.0	98.0	-
67.0	83.2	46.3
40.9	44.4	24.4

dorsal valve, faint, elongated, striated impressions as of muscles may sometimes be seen a short distance below the umbo.

Description of Lectotype: The lectotype, P. M. O. 12431 (Plate IV, figs. 1—3) is a well preserved specimen of average size, in which the shell-substance is present. The dorsal umbo is incurved beneath the ventral umbo; the hinge-line is short and nearly straight. The outline is sub-oval; in profile, the ventral valve is slightly the more convex. There is in each valve a shallow, median furrow with a lateral furrow on either side. Concentric growth-lines are prominent towards the anterior margin.

Remarks: *Holorhynchus giganteus* may be identified externally by its smooth, large shell, of sub-oval outline, with the occasional radiating furrows, while internally the absence of a median septum and the form of the cardinalia are characteristic. The possession of a free spondylium is a feature which it shares among Pentamerids only with *Cymbidium* Kirk. In that genus, too, there is no direct evidence that the spondylium had previously been sessile. In *Holorhynchus*, Kiær evidently considered that the septum had been secondarily lost (1901, pp. 77, 109), and he suggested that the development of the unusually thick shell in the posterior of the ventral valve, was a complementary effect which might, for example, afford a more rigid attachment for the spondylium at its junction with the valve-wall, along the margin of the delthyrium.

In the dorsal valve the cardinalia are of the greatest interest; these have but little, apparent relationship to the cardinalia of a *Pentamerus*, but are much more closely allied to the structures in the dorsal valve of species of *Stricklandia* (cf. text-fig. 9 with figs. 20 to 21). The common Norwegian *Stricklandias*, *S. lens* and *S. lirata*

have very short, ventral, median septa, while the prominence of the genital markings is another point of resemblance between the two genera, as Kiær noticed (1901, pp. 76, 108). Their relationships have been discussed at greater length in the morphological section.

Kiær recorded *Holorhynchus* from zone 5 b at Sandvika, Asker, the locality which has yielded most of the material in his collection, and also from Vestre Svartøy, Ringerike, at the same horizon. Outside Norway the genus has as yet been reported only from Northern Sweden (Kulling, 1933).

Genus *Conchidium* W. Hisinger 1799.

[ex C. Linnaeus 1768].

Linnaeus, C., *Systema Natura*, Ed. XII, Tom. III, 1768, p. 163. [Usage not binominal, cf. pp. 259—260 of present paper.]

Hisinger, W., "Minerographiske anmärkningar öfver Gottland", *K. svenska Vetensk. Akad. Handl.*, Tom. XIX for 1798 (1799), p. 285.

Wahlenberg, G., "Petrificata Telluris Svecanae examinata", *Nova Acta Soc. Sci. Upsal.*, VIII, 1821 (1819), p. 67 [*nomen nudum*].

Oehlert, D. P., in P. H. Fischer's "Manuel de Conchyliologie", 1887, p. 1311

Hall, J. and Clarke, J. M., *Palaeontology of New York*, VIII, pt. ii, 1894, pp. 231—5.

Schuchert, C. and Cooper, G. A., "Brachiopod Genera of the Suborders Orthoidea and Pentameroidea", *Mem. Peabody Museum nat. Hist. Yale*, IV, pt. i, 1932, pp. 181—3.

Synonyms: *Gypidia* Dalman, J. W., *K. svenska Vetensk. Akad. Handl.* (for 1827), 1828, pp. 125, Taf. IV, figs. 1 a—g.

[?] *Pentamerus* Pander, C. H., *partim*. [*non Pentamerus* J. Sow. 1813], *Beitr. Geogn. Russ. Reiches*, 1830, p. 94.

[?] *Antirhynchonella* Quenstedt, F. A. von, *Petref. Deutsch*, Vol. II, p. 231 (1869).

Pentamerus Caldwell, F. E. S. [*non Pentamerus* J. Sow. 1813; *non Pentamerus* C. H. Pander 1830], *Abstr. geol. Soc. Lond.*, No. 1315, 1936, p. 116.

Genoholotype: *Conchidium bilocularis* W. Hisinger 1799 [ex Linnaeus 1768], *K. svenska Vetensk. Akad. Handl.*, XIX for 1798, p. 285.

The specimen figured by Linnaeus (*Museum Tessinianum* 1753, Tab. V, figs. 8 A and B), has the greatest value as a type.

Generic Description: (Partly after Schuchert and Cooper, 1932). Sub-oval to sub-triangular, multicostate Pentamerids, rather strongly biconvex. Hinge-line short. Ventral valve always the higher,

with a prominent umbo. Umbones often incurved, the ventral arched forward over the dorsal. A concave pseudodeltidium covering the apex of the delthyrium, is present in the type species (cf. Schuchert and Cooper, 1932, pp. 181—2). A long and rather narrow spondylium in the ventral valve, supported on an extremely long, duplex septum.

The cardinalia in the dorsal valve, seem to show the usual tripartite division into inner-plates, brachial-processes and outer-plates, but the division between the two last may be indistinct. Brachial-processes very long, extending beyond the inner-plates and outer-plates to about the same length as the spondylium. Dentition simple, similar to *Pentamerus*.

European Species:

Pentamerus bashkiricus E. de Verneuil 1845.

Anomia (*Conchidium*) *bilocularis* W. Hisinger 1799 [ex Linnaeus 1768].

Synonyms: *Anomites conchidium* G. Wahlenberg 1819.

Gypidia conchidium J. W. Dalman 1828.

Pentamerus hercynicus A. Halfar 1879. (Short septate form.)

Pentamerus (*Gypidia*) *karpinskii* T. N. Tschernyschew (= Chernuishev) 1893.

Pentamerus knightii J. Sowerby 1813.

Conchidium münsteri new species [J. Kiær MS.].

Pentamerus pseudoknighti T. N. Tschernyschew (= Chernuishev) 1893.

Pentamerus rossicus A. P. Karpinsky 1893[?].

*Pentamerus sculptus*¹ N. P. Angelin and G. Lindström 1880.

*Pentamerus tenuistriatus*¹ N. P. Angelin and G. Lindström 1880.

Pentamerus vogulicus E. de Verneuil 1845.

[?] *Pentamerus aylesfordii* J. Sowerby 1813 (? Synonym of *P. knightii*).

[?] *Pentamerus firmus* J. Barrande 1879.

Of the European species referable to *Conchidium*, *C. münsteri* Kiær MS. is a *nomen nudum* and is described for the first time in the present paper. *Pentamerus pseudoknighti* Tschern., it would seem from Tschernyschew's figures may only be a small, incurved variety of *P. vogulicus* de Vern. *P. aylesfordii* J. Sow. is generally regarded as a synonym of *P. knightii* J. Sow. The fourteen species described by Pander (1830, pp. 92—5, pls. ix—x) under the generic name

¹ These two species are mentioned by name only in Lindström 1861 pp. 365, 380.

Pentamerus, cannot belong to that genus. Being ribbed forms, it might be thought that they were species of *Conchidium*, but to judge from Pander's figures it is very doubtful whether they should be considered as Pentameracea at all, and some at least are probably more correctly referred to Lahusen's genus *Lycophoria*.

Conchidium münsteri new species [Kiær MS.].

Plates V, figs. 9 and 11; VI, figs. 10—11; Text-figs. 7 and 10.

1897. *Pentamerus münsteri* Kiær, J., "Faunistische Übersicht der Etage 5 des norwegischen Silursystems", *Vidensk. Selsk. Skrifter, Math.-Naturv. Kl.* (1897), No. 3, pp. 7, 30, 32, 76 [*nomen nudum*].
1901. *Conchidium münsteri* Kiær, J., "Etage 5 i Asker ved Kristiania", *Norg. geol. Unders., Aarbog for 1902*, No. 1, 1901, pp. 80, 110 [*nomen nudum*].

Material: P. M. O., specimens 15 132—42, 16 644—52, 16 665—74, 20 821 (Kiær Collection), all from Vestre Svartøy, Ringerike, southern Norway.

Holotype: specimen P. M. O., 20 821 a, cf. Pl. VI, fig. 11 from zone 5 b, Vestre Svartøy, Ringerike, southern Norway.

Paratypes: specimens P. M. O., 20 821 b, c (originally from the same block as the holotype), cf. Pl. VI, fig. 10.

Topotypes: the remainder of the material as listed above.

The name *Conchidium münsteri* was twice mentioned by Kiær, when discussing the fauna of zone 5 b, but the species has never been described or figured. The specimens in the Kiær Collection occur as broken and isolated shells in a hard limestone matrix and are all ventral valves.

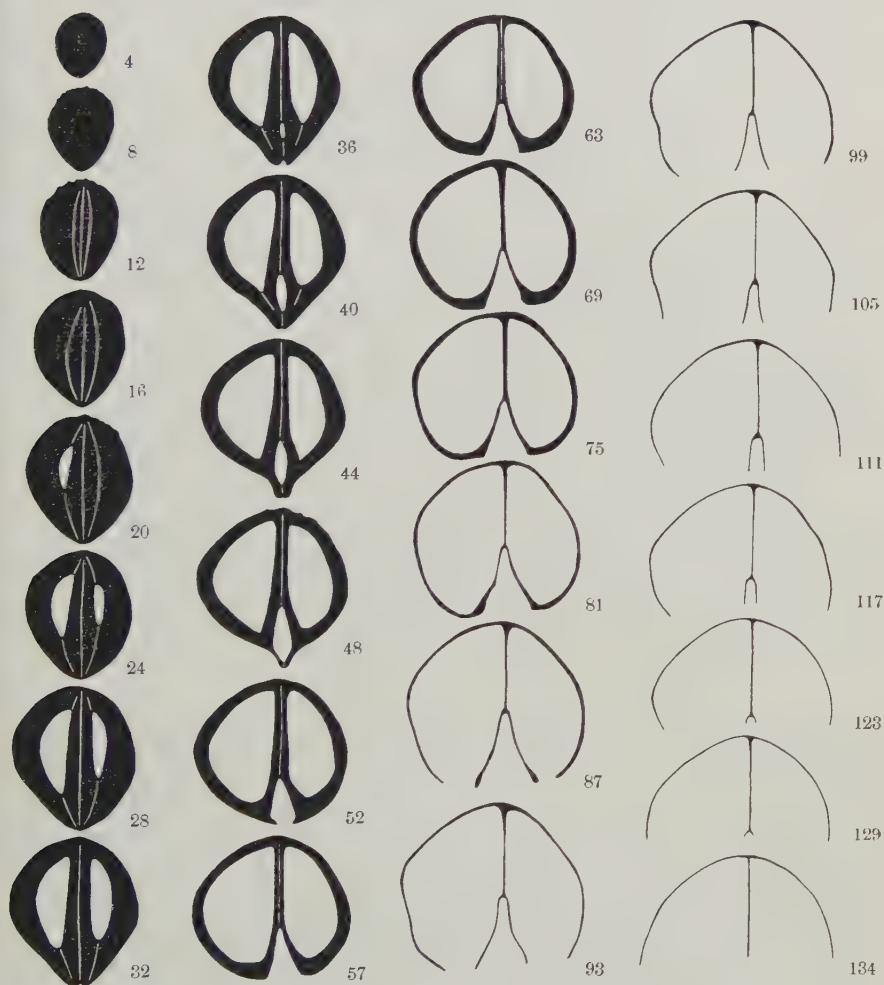
Diagnosis: Small *Conchidium* with a rather convex, ventral valve and moderately incurved umbo (Pl. VI, figs. 10—11). Outline sub-triangular, the greatest breadth is attained towards the anterior margin. Valve-surfaces with numerous small, radiating costae. In the ventral valve a large delthyrium of which the antero-dorsal corners are slightly expanded to serve as teeth. A long and deep spondylium, narrowing rapidly anteriorly to the delthyrium, supported on a thin, high, duplex, median septum, which extends beyond the spondylium almost to the anterior margin of the valve.

Discussion: The relative dimensions may only be estimated approximately since the dorsal valve is unknown. The species is rather elongate in outline, particularly so in young specimens. The

maximum length was probably considerably greater than both the breadth and the thickness. The ventral umbo is somewhat flattened and appears to have been only slightly higher than the dorsal. The surface of the ventral valve is folded into fine costae, most of which commence near the umbo (Pl. VI, fig. 10), but occasional new costae arise by bifurcation. 8 to 10 costae occur to the centimetre, and about 30 may be present round the anterior margin. The valve-surface is usually smooth below the umbo and also along the lateral margins. Concentric growth-ridges may be present. The shell-wall is thickened towards the posterior, but anteriorly is very thin.

Internal Characters: The species shows a typical development of the long spondylium and very long septum that characterize the genus (Pl. V, figs. 9, 11). The septum may frequently be observed on the exterior of specimens, extending almost to the anterior margin. It has been traced by serial sections as in the case of *Pentamerus*, to the extreme posterior end of the valve, where it is embedded in the thickened valve-walls (text-fig. 10, transfers 8 to 24). Soon after it separates as a discrete structure, it divides to enclose the spondylial cavity below the umbo (transfers 36 to 57). The septum becomes higher and less thick towards the anterior, and for the greater part of its length is relatively thin (transfers 75 to beyond 150). Its duplex character is clearly maintained throughout its length. The spondylium decreases rapidly in size below the hinge-line (Pl. V, figs. 9, 11); posteriorly the spondylial cavity is rather acutely triangular in section (text-fig. 10, transfers 69 to 93), anteriorly, the walls may become parallel-sided. Where the edges of the spondylium first separate from the valve-wall (transfers 87), they are thickened to serve as teeth.

The thin layer within the spondylial cavity that has been observed in *P. laevis* and *P. cf. gotlandicus* is present also in this species of *Conchidium*. In specimen A. 13509 it can be seen in transfers 36 to 50 (cf. text-fig. 7, II) lining the apex of the delthyrial cavity; it may have a slight extension along the plane of the median septum. It decreases in thickness anteriorly and has not been definitely seen much below the hinge-line. In the few specimens that have been sectioned a pseudodeltidium is not present nor is the covering layer thickened along the delthyrial margins (as in *P. laevis* and *P. gotlandicus*), as would probably have been the case, had such a structure existed in life.



Text-fig. 10 *Conchidium münsteri* new species.

Serial transfers (S. M. C. A. 13509) at 0.125 mm intervals from the posterior end of a specimen; zone 5 b, Ringerike. $\times 1\frac{1}{2}$. Transfers 4—134.

(Cf. text-fig. 7 and Pl. V, figs. 9, 11).

Dimensions (in millimetres).

Length	Breadth
24.8	22.9 { (present dimensions of holotype)
25.0	22.0 Paratype 20 821 b
18.0	20.0 Paratype 20 821 c

Description of Holotype: The holotype, P. M. O. 20821 a (Pl. VI, fig. 11) is the ventral valve of a specimen of average size, which is broken near the anterior margin almost at the end of the septum. The triangular delthyrium is clearly seen.

Remarks: This species, known only from zone 5 b in southern Norway, is the earliest *Conchidium* at present recognized; all the American forms as well as those from the Baltic States, belong to the Upper Silurian. Although it is separated in time from the other species of this genus by the whole of the Llandovery period, *C. münsteri* possesses the typical, long septum and spondylium of the later forms. It appears to be most closely allied to *C. bilocularis*, the type species from which it differs in its rather less triangular outline, in its lower and more incurved ventral umbo, and its finer costae.

Genus *Clorinda* J. Barrande 1879.

Barrande, J., "Système Silurien du Centre de la Bohême", Vol. V, 1879, p. 109.

Hall, J. and Clarke, J. M., Palaeontology of New York, Vol. VIII, pt. ii, 1894, pp. 241, 245.

Kozłowski, R., "Les Brachiopodes Gothlandiens de la Podolie Polonaise", *Palaeont. polon.*, I, 1929, pp. 137—9.

Schuchert, C. and Cooper, G. A., "Brachiopod Genera of the Suborders Orthoidea and Pentamerioidea", *Mem. Peabody Museum nat. Hist. Yale*, IV, pt. i, 1932, pp. 171—2.

Synonym: *Barrandina* Booker, F. W., *J. roy. Soc. N. S. W.*, vol. 60, 1926 (1927), p. 131.

Genoholotype: *Clorinda armata* J. Barrande, Syst. Sil. Bohême, vol. V, 1879, p. 109, pl. 119, figs. 1—4.

Generic Description: Barrande's original account is quoted in full:

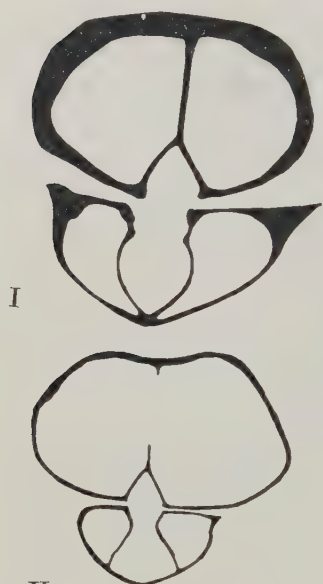
"*Clorinda* Barr., Pl. 119 [of Syst. Sil. Bohême] reproduit par sa forme extérieure les apparences bien connues de *Pentam.*

linguifer Sow. Cette ressemblance est si trompeuse, que nous avons pendant longtemps réuni ces Brachiopodes sous les mêmes noms générique et spécifique. Mais, tandis que *Pentam. linguifer* figuré sur nos Pl. 22—24. . . . nous montre distinctement les cloisons et compartiments internes, caractéristiques de ce genre, *Clorinda* Pl. 119 est représentée par une série de spécimens, dont le moule interne offre une structure entièrement différente. Cette structure ne se retrouvant à notre connaissance, dans aucun autre Brachiopode figuré jusqu'à ce jour, nous avons cru devoir la considérer comme justifiant l'établissement du nouveau genre *Clorinda*.

Nous ferons remarquer, que les moules internes figurés sont composés de silice, qui s'est substituée au corps du mollusque. Par suite probable de la différence d'âge, ces spécimens, conservant les mêmes dispositions typiques, offrent cependant entre eux de notables différences individuelles. Dans tous, on reconnaît une partition médiane sous la forme d'un angle, compris entre des arêtes saillantes, dont le sommet est placé au crochet de la valve ventrale. La structure de la valve dorsale nous est inconnue.

Au type *Clorinda armata*, trouvé dans nos bandes f 2—g 1, nous adjoignons, avec quelque hésitation, une autre forme reproduisant aussi extérieurement celle de *Pentam. linguifer* et analogue au type *Clorinda* par les apparences moins prononcées de son moule interne. Nous la nommons *Clorinda ancillans* et elle est figurée sur la même pl. 119. Elle provient de notre bande e 2."

Barrande's figures (*op. cit.*, pl. 119, figs. 1—4) show four specimens from Hlubočep, horizon gl. There appears to be a short, median septum in the ventral valve, while in the only direct view (fig. 4 c) of a dorsal valve, the structure is not very clear. Externally, the specimens bear a close resemblance to *Barrandella linguifera* (J. de C. Sow.) 1839, the genotype of *Barrandella* Hall and Clarke, 1894 (p. 241). This latter genus has been considered a synonym of *Clorinda*, but more recently the name has been revived by Kozłowski (1929) and Schuchert and Cooper (1932). Kozłowski's detailed treatment (1929, pp. 127—9) of the Polish species *Clorinda pseudo-linguifera* Koz. 1929, shows this to have a different arrangement of the brachial-processes in the dorsal valve from that in *Barrandella linguifera* (J. de C. Sow.) 1839, justifying their generic separation. After Schuchert and Cooper 1932, *Barrandella* and *Clorinda* are here regarded as distinct genera, rather than as genus and sub-genus (as Kozłowski), because in each genus the structures in the



Text-fig. 11.

Transverse sections of (I) *Barrandella linguifera* (J. de C. Sow.) S. M. C. A. 13521 $\times 5$, and (II) *Clorinda undata* (J. de C. Sow.) S. M. C. A. 13512, $\times 3$.

dorsal valve have the same value in taxonomy there being nothing yet to show that either genus is descended from the other.

The two genera are generally similar in external form, and in the structures of the ventral valve, but the characteristic distinguishing feature is the dorsal interior. In *Clorinda* the dorsal septa are subparallel or divergent as they approach the valve-floor, while in *Barrandella* they are always markedly convergent, uniting to form an almost sessile cruralium (text-fig. 11). With regard to this difference the one caveat must be entered that the genoholotype of *Clorinda* is *C. armata* Barrande, a species in which Barrande stated (cf. the quotation above) that the structure of the dorsal valve was unknown. Should this species be found to have convergent cardinalia, *Barrandella* would become a synonym of *Clorinda* and a new generic name would be required for species with dorsal, internal structures of the type of *Clorinda pseudolinguifera* Koz. 1929.¹

¹ Kozlowski (1929, p. 139, footnote 1) also states that the internal structures of *C. armata* Barr. and *C. ancillans* Barr. are unknown. His argument that they are probably as in *C. pseudolinguifera* Koz., because of their close external similarity to the specimens determined by Barrande as *Pentamerus linguifera* (and really *C. pseudolinguifera*) loses much of its force because of the marked similarity between *Pentamerus* (*Barrandella*) *linguifera* and *C. pseudolinguifera* themselves. Thus, the originals of Barrande's figs. 9 and 10 (*op. cit.* pl. 119), evidently possess two discrete septa in the dorsal valve (figs. 10 c and 10 e), and hence should be, apparently, *C. pseudolinguifera* rather than *B. linguifera* as he identified them. The species *Clorinda armata* is unrepresented in the collections of the British Museum (Natural History), London, and the Sedgwick Museum, Cambridge, and no specimens have been available to the present writer.

European Species:

Clorinda ancillans J. Barrande 1879.

Clorinda armata J. Barrande 1879.

Atrypa globosa J. de C. Sowerby 1839.

Clorinda groenlandica C. Poulsen 1934.

Barrandella kjerulfi J. Kiær 1901.

Clorinda malmøensis new species.

Clorinda pseudolinguifera R. Kozłowski 1929.

Atrypa undata J. de C. Sowerby 1839.

[?] *Pentamerus bubo* J. Barrande 1847 (?synonym of *C. undata*).

[?] *Pentamerus krasnopolskii* T. N. Tschernyschew (= Chernuishev) 1893 (?synonym of *C. undata*).

[?] *Pentamerus sublinguifer* F. Maurer 1885 (*teste* Leidhold 1928).

Examination of the common Norwegian forms, "*Barrandella*" *kjerulfi* Kiær and "*Barrandella*" *undata* (J. de C. Sowerby), shows that they should more properly be referred to *Clorinda*. The last species and the closed allied "*Atrypa globosa*" J. de C. Sowerby, are also of widespread occurrence in Britain.

Clorinda kjerulfi (J. Kiær) 1901.

Plates VII, figs. 1—6. VIII, figs. 1—3; Text-figs. 12 and 13.

1901. *Barrandella kjerulfi* Kiær, J., "Etagé 5 i Asker ved Kristiania", *Norg. geol. Unders.* [Aarbog for 1902], No. 1, 1901, pp. 63—8, figs. 1—7 on p. 64, and pp. 100—3, (English Summary).

Material: P. M. O., specimens 12545—51, —79, —83, —85—89, 12595—606, 12613—20, —26, —50, —53, 12673—90, 20508, 40466.

Lectotype (chosen by Dr. T. Strand in MS.): specimen P. M. O. 12598, figured Kiær, *op. cit.*, p. 64, figs. 1—4, from zone 5 b, south of Halden, Asker, southern Norway. Cf. Pl. VII, figs. 1, 4; text-fig. 12, I.

Paratypes: Specimens P. M. O. 12595—97, 12599—606, from the same horizon and locality, 40466 from zone 5 b, Jørgensløkken, Asker. Specimens 12595 and 40466 were figured by Kiær, *op. cit.*, p. 64, figs. 7 and 5—6 respectively. Cf. also Pl. VII, figs. 2, 3, 5, 6.

Diagnosis: Small, rather transverse *Clorinda* with the ventral umbo usually only slightly higher than the dorsal. Hinge-line, short, curved. Low, median, dorsal fold and ill-defined, ventral sinus. Valve-surfaces folded into a few, small, radiating costae which are mainly

developed on the anterior half of the shell. In the ventral valve, a triangular delthyrium and small spondylium supported on a thin, very short, duplex septum. Spondylial cavity shallow. In the dorsal valve the cardinalia are slightly divergent, the carinae at the junction of the inner-plates with the brachial-processes are indistinct or absent. Brachial-processes lamellar.

Discussion: The dimension of breadth is commonly a little greater than the length and considerably greater than the thickness. The maximum breadth is attained about half-way towards the anterior margin, producing a sub-rhombic outline. Kiær (1901, pp. 65, 100) recognized two distinct forms a broad *e. g.* the lectotype; Pl. VII, figs. 1, 4), and a narrow form (*e. g.* paratype 40466, Pl. VII, figs. 3, 6). The differences may readily be appreciated by referring to the table of dimensions. The extreme types are connected by many intermediates, and have been proved by serial-sectioning to have precisely the same internal structure.

The ventral valve is generally more convex and a little higher than the dorsal valve. The ventral umbo is seldom prominent, it is usually slightly curved forwards, close to the dorsal umbo (Pl. VII, figs. 1—6). In a few individuals the umbones are of about the same height. There is no well-defined cardinal-area. The dorsal valve has a definite, but small median fold. This commences a little below the umbo and increases in width anteriorly; similarly in the ventral valve there is a shallow median sinus which projects as a slight tongue into the dorsal fold at the anterior margin (text-fig. 12). The anterior portion of the shell is folded into small, rounded, radiating costae, of which two to five may be present on either side of the fold and sinus. These are best developed in large specimens, but vary considerably in prominence and are sometimes indistinct or absent. The ventral sinus is usually divided by a small costa, while a very shallow furrow commonly bisects the dorsal fold.

Articulation takes place between the thickened margins of the spondylium just below the corners of the delthyrium and the inner-plates in the dorsal valve (text-fig. 13, transfers 26 to 30). There is usually a much closer fit between the two structures than in species of *Pentamerus*.

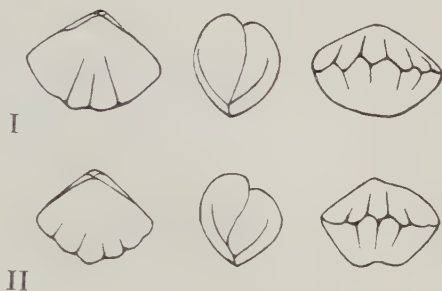
Internal Characters: The outline of the delthyrium is approximately that of an equilateral triangle (Pl. VIII, fig. 1). The dental-plates join the valve-wall along the margins of the delthyrium

and continue anteriorly to form a short spondylium. At the level at which they separate from the hinge-line the spondylial walls meet almost at right-angles (text-fig. 13, transfers 22 to 30) and the spondylial cavity in thus relatively broad and shallow: towards the anterior it becomes very small as the edges of the spondylium approach each other (text-fig. 13, transfers 38 to 50; Pl. VIII, fig. 1). The spondylium may extend for a little more than

a third of the distance from the umbo to the anterior margin. The supporting septum is very short, it usually ends before the spondylial walls separate from the hinge-line (text-fig. 13, transfers 16 to 18). In specimen P. M. O. 12673, it extended for rather less than 2 mm below the umbo, so that the spondylium is free for the greater part of its length.

The duplex character of the septum is never so distinctly marked as in the species of *Pentamerus*. It is clearest at the posterior margin where the septum is still embedded in the shell-material of the valve-wall, anteriorly it may be quite lost. A thin layer lining the spondylial cavity does not appear to occur in this species, or at least is not clearly separable from the rest of the shell-material. A pseudodeltidium has never been observed.

The cardinalia in the dorsal valve are divergent, as is usual in *Clorinda*. The junctions between the different plates are usually indistinct in thin sections; thus, in the specimens that have been serial-sectioned no division can be observed between the outer-plates and the bases of the brachial-processes. The inner-plates, however, may be seen sharply inclined outwards from the latter towards the margins of the spondylium (text-fig. 13, transfers 28 to 34). The brachial-processes (= 'crura') separate relatively early (transfers 30 to 32) from the valve-wall and continue for a long distance beyond the end of the inner-plates (transfers 36 to 54), often exceeding the length of the spondylium. The brachial-processes are in the form of flattened



Text-fig. 12.

Clorinda kjerulfi (Kiær).

Outline drawings of the dorsal, right-lateral and anterior views of (I) the lectotype P. M. O. 12598 and (II) paratype P. M. O. 12599 a. Natural size.

Dimensions of Typical Specimens
(in millimetres).

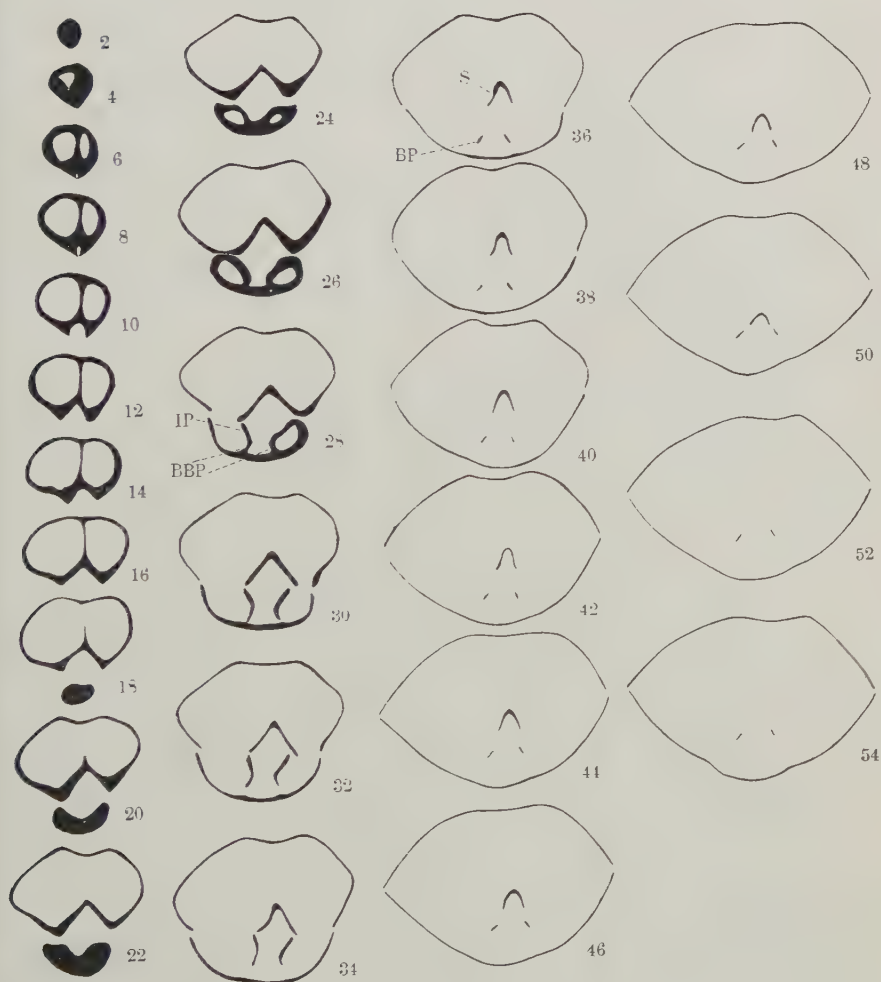
Length	Breadth	Thickness
12.8	16.8	11.3 (Lectotype)
8.3	9.1	6.0 (Paratype)
10.3	9.6	8.4 (Paratype)
9.7	12.3	6.7
14.1	18.0	11.0
16.6	16.3	11.1
11.6	13.9	11.0
10.4	9.6	8.8
12.0	11.0	7.4
20.0	21.5	-

rods, or narrow lamellae; they are sub-parallel, with their axes inclined inwards to one another.

Description of Types: The lectotype (Pl. VII, figs. 1, 4) is a rather large specimen of the broad variety. It is sub-rhombic in outline, the ventral valve is slightly the more convex, and the ventral umbo rather low. On each side of the median fold and sinus, which are clearly developed, two to three costae are present. The paratypes (Pl. VII, figs. 2, 3, 5, 6) include specimens of both broad and narrow shape variations.

Remarks: *Clorinda kjerulfi* differs from most other species of *Clorinda* in the presence of small costae on the anterior portion of the shell. These are always few in number and rather resemble the similar feature in certain species of *Gypidula* (*i. e.* *G. galeata*). The dorsal fold is often somewhat sharply delimited as in *C. pseudolinguifera*, though it never attains the proportions reached in that species. The small carina at the junction of the inner-plates with the bases of the brachial-processes, which has been described by Kozłowski in *C. pseudolinguifera*, and by Booker in certain Australian species perhaps to be referred to the same genus, is seldom well developed in *C. kjerulfi*. Kiær (1901, pp. 66, 102) considered that *C. kjerulfi* was most closely related to '*Barrandella*' *areyi* Hall and Clarke from the Clinton Group, U. S. A., a form of which the internal structure is unknown.

All the material in the Collection is from zone 5b at various localities in the Asker district, the only area from which the species is recorded. The details of its distribution have been discussed by Kiær (1901, pp. 28—31).

Text-fig. 13. *Clorinda kjerulfi* (Kjær).

Serial transfers (S. M. C. A. 13510) at 0.125 mm intervals from the posterior end of a specimen; zone 5 b, Asker. Transfers 2-54. $\times 2$. (Cf. Pl. VIII, figs. 1, 2 and 3).

BBP $\times$ bases for the brachial-processes; BP = brachial-processes;

IP = inner-plates; S = spondylium.

Clorinda undata (J. de C. Sowerby) 1839.

Plates VI, figs. 1—9; VII, figs. 13—15; VIII, figs. 4—7;

Text-figs. 14—16.

1839. *Atrypa undata* Sowerby, J. de C., in Murchison's "Silurian System", p. 637, pl. 21, fig. 2.
1867. *Pentamerus undatus* (J. de C. Sow.). Davidson, T., "British Fossil Brachiopoda", *Palaeontogr. Soc. Lond. [Monogr.]*, III, pt. vii, pp. 155—6, pl. xix, figs. 4—9 (with Bibliography). *Idem*, V, pt. ii (1883), pp. 162, pl. ix, figs. 10—20.
1908. *Barrandella undata* (J. de C. Sow.). Kiær, J., "Das Obersilur im Kristianiagebiete", *Vidensk. Selsk. Skrifter, Math.-Naturv. Kl.* (1906), II, *passim*.
 [?] Synonyms. *Pentamerus bubo* Barrande, J., *Naturw. Abhandl.* (Haidinger), I, 1847, 472—4, pl. xxii, figs. 2a—d.
Pentamerus krasnopolskii Tschernyschew (= Chernuishev), T. N., "Die Fauna des unteren Devon am Ostabhange des Ural", *Mém. Com. géol. St.-Pétersb.*, vol. IV, No. 3, p. 79, Tab. XIII, figs. 1—4.

Material: P. M. O. specimens 20858—60, —63—65, —67, —69—71, 21242, 41253, —57—68, 41296—304, 41323—27, —52, 41650—65, 42490—91, 43400—02, —48—9, 43530, 52035—38, —42, 52101—08, —34, —36, —40, 52362, 52550—51, 52600, —03—04, —07, 52826, 52926, —29—31, —55, 53055—56, 53569—72, 53714—15, 54900—01, —06, 58564—65. From various localities in southern Norway.

Syntypes: The three specimens figured by J. de C. Sowerby *op. cit.*, 1839, pl. 21, fig. 2. The original of the bottom, left-hand figure is now preserved in the Collection of the Geological Survey, London (No. 7612, from the Lower Llandovery of Cefn-y-garreg, Carmarthenshire). Cf. Pl. VI, fig. 7; the other two specimens appear to be lost.

Clorinda undata is a very common fossil in the Llandovery of southern Norway as also in Great Britain; though it has in the past commonly been referred to *Barrandella*, an examination of its internal structures shows that it is really a species of *Clorinda*.

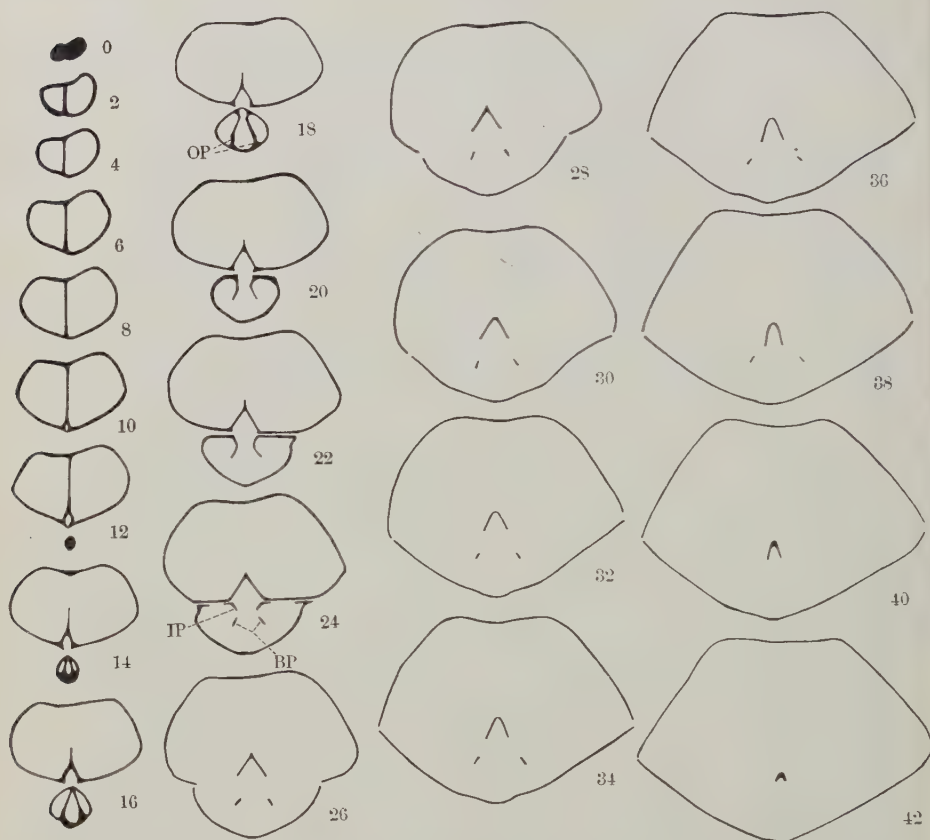
Diagnosis: Large, smooth, transverse *Clorinda* with the breadth usually much greater than the length, and the ventral valve considerably more convex than the dorsal (Pls. VI, figs. 1—9; VII, figs. 13—15). Umbones approximate, the ventral umbo rather low, incurved. Hinge-line long, straight. Large, prominent, flattened, median, dorsal fold, and shallow ventral sinus. Anterior margin strongly uniplicate. In the ventral valve a small delthyrium and short, narrow

spondylium, with short, supporting septum. In the dorsal valve the cardinalia consist of strongly divergent crural-plates, composed of inner-plates, brachial-processes and outer-plates (text-fig. 15). A small carina may be present at the junction of the inner-plates and the bases of the brachial-processes. Inner- and outer-plates very small: brachial-processes slender, diverging, rather long.

Discussion: The outline of this species is generally elongate-oval; the ventral valve is higher than the dorsal but seldom projects far above the hinge-line (Pls. VI, fig. 4; VII, fig. 13). The ventral umbo is much incurved and comes to lie in the adult considerably below the posterior end of that valve (Pl. VIII, figs. 4, 5). The hinge-line extends for about three-quarters of the maximum width of the shell. The lateral margins are nearly semi-circular; the anterior side of the valves when seen in the dorsal aspect, almost straight.

The fold in the dorsal valve is always well developed. It commences at the umbo and increases in width anteriorly, being generally rather triangular in outline, and with a flattened or gently convex surface. At the anterior margin the sides of the fold may be nearly parallel, arising almost at right-angles from the rest of the valve. The fold produces a strong, sub-rectangular plication of the margin (Pls. VI, figs. 3, 6, 8; VII, fig. 15). The sinus of the ventral valve is less prominent than the fold; it commences a little below the umbo and deepens anteriorly, where at the margin it extends as a tongue into the dorsal fold (Pl. VI, figs. 3, 6, 8). The sinus is frequently divided longitudinally by a low, median plication (*e. g.* P. M. O. 52 136). In some individuals (P. M. O. 41 262, 53 714) it is ill-defined or absent. In specimens in which the shell-substance is well preserved, concentric growth-lines are well marked especially towards the anterior.

Internal Characters: Owing to the incurving of the ventral valve the umbo does not lie far above the hinge-line and the delthyrium is consequently small. Occasionally, very slight ridges are present at the margins of the delthyrium (text-fig. 15), but these do not appreciably constrict the opening. When the valves are in apposition it is largely covered by the dorsal umbo. The spondylium is very short, and curves antero-dorsally towards the interior of the dorsal valve (Pl. VIII, fig. 5). The spondylial cavity is shallow, its cross-section approximates to an equilateral triangle (text-fig. 14, transfers 20 to 36). The supporting septum is thin and short (text-fig. 14, transfers 2 to 12), it seldom extends much below (*i. e.* anterior to) the level of the

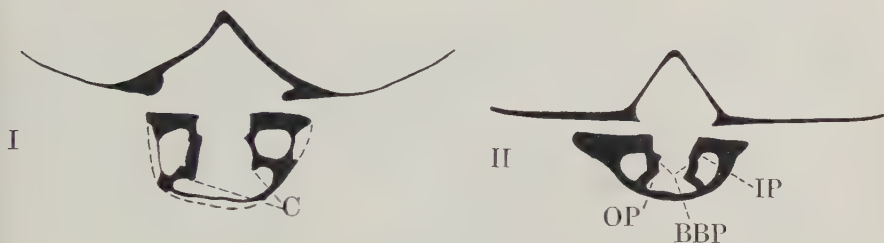


Text-fig. 14. *Clorinda undata* (J. de C. Sowerby).

Serial transfers (S. M. C. A. 13 512) at 0.125 mm intervals from the posterior end of a specimen; zone 6a, Sjørøys, Oslo. $\times 2$. Transfers 0—42. (Cf. VIII, figs. 4—7. BP=brachial-processes; IP=inner-plates; OP=outer-plates.

apex of the delthyrium. It is seen to be duplex in character where it separates from the valve-wall, but anteriorly, the median plane of division along the septum is usually indistinct.

In the dorsal valve the crural-plates are very small, extending only for a short distance below the umbo. Posteriorly, they may often be seen to be rather distinctly divided into inner-plates, bases of the brachial-processes and outer-plates (text-figs. 14, transfer 18, and 15). At the junction of the inner-plates with the bases of the brachial-processes a small carina may be present and sometimes, also, at the junction of the latter with the outer-plates. The appearance



Text-fig. 15. *Clorinda undata* (J. de C. Sowerby).

Transfers from two specimens, $\times 5$. From left to right S. M. C. A 13 513 (42) and A. 13 514 (36). BBP=bases of the brachial-processes; C=carinae; IP=inner-plates; OP=outer-plates.

of these carinae is due to the bases of the brachial-processes being rather strongly concave to one another (text-fig. 15), and not entirely in the same plane as the inner- and outer-plates. The outer-plates always diverge strongly and are widely separated where they join the valve-wall. The brachial-processes consist of straight lamellae, which often continue as far as, or beyond the end of the spondylium (text-fig. 14, transfers 24 to 38).

Internal casts — a common form of occurrence of the species in Britain — show a short, median furrow in the ventral valve, which marks the position of the septum, while in the dorsal valve two extremely small slits may occasionally be seen, indicating the presence of the separate, crural-plates. Rather irregular, longitudinal ridges which appear to be pallial markings are often prominent in internal casts of the ventral valve. In one specimen (S. M. C. A. 13 551; text-fig. 16) they may be seen to conform to a definite arrangement. An area covered with small rugosities probably indicating ovarian markings commonly occurs on either side of the ventral, median, septum.

Description of Types: The syntype figured on Pl. 21, fig. 2 (bottom, left-hand figure) of "The Silurian System" 1839, is an almost complete internal cast of a rather transverse dorsal valve,¹ showing slight traces of median muscle-impressions (cf. Pl. VI, fig. 7).

Remarks: *Clorinda undata* is easily distinguished from other species of this genus by its smooth, transverse shell, its prominent

¹ [?] Not ventral as stated by Davidson. The specimen was republished by Davidson (1867, pl. xix, fig. 7), whose figure is a mirror image of the original.



Text-fig. 16.

Clorinda undata
(J. de C. Sowerby).

Internal cast of a
ventral valve show-
ing pallial markings,
S. M. C. A. 13551.

$\times 1\frac{1}{4}$ approx.

dorsal fold and low ventral umbo. It is closely related to *Clorinda globosa* (J. de C. Sow.), which species, however, has a more strongly biconvex and less transverse shell and, apparently, a rather larger, ventral septum. Intermediate varieties do occur, and such specimens as P. M. O. 41323 and 53570 which are strongly inflated and less transverse than the typical *C. undata* serve to connect the two species. *C. pseudolinguifera* Koz. has a more rounded outline, a less convex dorsal valve and a higher ventral umbo.

Internally, *C. undata* possesses a septum of about the same length as that in *C. kjerulfi* (Kiær) and rather shorter than that of *C. malmøyensis*.

The thickenings along the sides of the delthyrium appear to be similar to those in *C. pseudolinguifera* termed by Kozłowski 'deltidial plates'. In the dorsal valve there is a much more distinct tripartite division of the cardinalia than has yet been recorded in any other species of the genus. The crural-plates are more strongly divergent, than in the two other Norwegian species and most closely resemble the arrangement in the specimen of *C. pseudolinguifera* figured by Kozłowski (1929, p. 137, fig. 40).

Pentamerus bubo Barr. from the Silurian of Bohemia, seems from a study of Barrande's figures to be identical in external characters with the present species. The same is true of *Pentamerus krasnopolskii* Tschern. and both names appear to be synonyms of *C. undata* (J. de C. Sow.).

Clorinda undata is common in horizons 6 and 7 of the Norwegian Silurian. At Ringerike it occurs in 6a and was considered by Kiær to be especially characteristic of this zone (1908, p. 42). In the eastern development at Malmøy, he chose it as the zone fossil for 6a β (*op. cit.*, pp. 135—7), and it continues in this district, though less commonly, through 6b to 6c. Its distribution in the Asker district is closely similar, it being particularly common in 6a α . The species occurs also in zone 7; there is a large, inflated form at Asker in 7a (P. M. O. 53569—70; cf. Kiær, *op. cit.*, p. 351) which approaches the related species *C. globosa*. The specimens in the upper part of this zone, referred by Kiær (*op. cit.*, pp. 155, 159) to *Barrandella linguifera* (J. de C. Sow.) are rather a variety of *C. undata*

Dimensions of Typical Specimens
(in millimetres).

Length	Breadth	Thickness
15.6 ¹	23.3	-
18.3	24.8	15.6
22.5	28.3	18.7
19.0	21.6	15.2
14.7	18.4	10.5
18.2	22.9	14.4
19.3	25.3	15.0
26.1	27.4	21.1
11.5	16.2	8.3
17.3	22.4	14.3

as is shown by a study of their internal structure. Thus, individuals from horizon 7c at Malmøy are less transverse than the typical *C. undata*, with a slight, angular furrow at the anterior margin on either side of the dorsal, median fold (P. M. O. 43 401—20).

*Clorinda malmøyensis*² new species.

Plates VII, figs. 7—12; VIII, figs. 8—9; Text-figs. 17—19.

1908. *Barrandella ventricosa* (J. Hall). Kiær, J., "Das Obersilur im Kristianiagebiete", *Vidensk. Selsk. Skrifter. Math.-Naturv. Kl.* (1906), II, pp. 166, 171, 589.

Material: P. M. O. specimens 21 350—52, 21 388—89 (over 50 individuals) all from Malmøy.

Holotype: specimen P. M. O. 21 389a, cf. Pl. VII, figs. 7, 10; text-fig. 17.

Horizon 8c, the lower part of the zone, from Malmøy (near Oslo).³

Paratypes: specimens P. M. O. 21 389b—k, S. M. C. A. 13 515, from the same horizon and locality.

The species *Clorinda malmøyensis* is proposed to include specimens from Malmøy referred by Kiær to *Pentamerus ventricosa* J. Hall 1860, a form which agrees internally with *Barrandella*,⁴ while the specimens in question have the internal structure of a *Clorinda*.

¹ Approximate, present dimensions of type.

² Named after Malmøy, the type locality.

³ Just to the east of the summit of the island, according to Kiær's label. Cf. Kiær, *op. cit.*, Karte III.

⁴ As may be seen from Hall and Clarke's figures. Cf. *e. g.*, 1894, pl. lxxi, fig. 5 showing in an internal cast, a single furrow in the dorsal valve, marking the junction of the united crural-plates with the valve-wall.



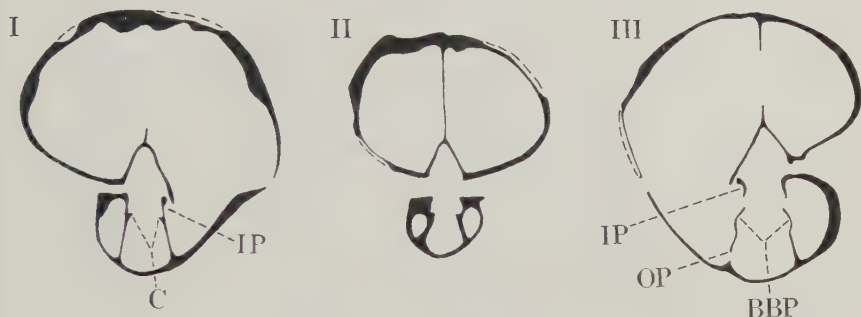
Text-fig. 17. *Clorinda malmøyensis* new species.

Outline drawings of the dorsal, right-lateral and anterior views of (I) the holotype P. M. O. 21 389 a and (II) paratype P. M. O. 21 389 c. $\times 2$.

Diagnosis: Small, transverse *Clorinda*, with a straight hinge-line and rounded lateral margins. Anterior margin uniplicate, with a low, median, dorsal fold and ill-defined ventral sinus. The greater part of the valve-surface folded into radiating costae, which commence below the umbones. In the ventral valve, a narrow delthyrium and a small spondylium supported on a short, median, duplex septum. In the dorsal valve, the cardinalia consist of small, divergent crural-plates from which there project relatively long, lamellar brachial-processes (Pl. VIII, fig. 9).

Discussion: This species is generally rather elongate-oval in outline with the breadth always exceeding the length and equal to about one-and-a-half times the thickness (cf. table of dimensions). The ventral valve is the more strongly convex (Pl. VII, figs. 7—12). The hinge-line is relatively long and may approach the greatest breadth of the shell. The median dorsal fold, though small, is always present, and produces a slight plication of the anterior margin. The ventral sinus is rudimentary. The valve-surfaces are folded into rounded, radiating costae (text-fig. 17), of which two compose the dorsal fold, while six or eight may be present round the margin.

When the valves are in apposition the posterior part of the edges of the spondylium are seen to project slightly dorsally from the commissure (text-fig. 19, transfers 11 to 13) to fit outside the margins of the crural-plates in the dorsal valve, articulation taking place between the two structures.



Text-fig. 18. *Clorinda malmøyensis* new species.

Transverse sections of three specimens, $\times 5$. From left to right

P. M. O. 21 389 d—f, respectively.

BBP=bases of the brachial-processes; C=carinae; IP=inner-plates;

OP=outer-plates.

Internal Characters: The delthyrium is short and narrow and in life would be partially covered by the incurved dorsal umbo (Pl. VIII, fig. 8). No constriction of the delthyrial opening has been observed. The spondylium is very small, it may attain a length of 3 or 4 mm measured from the umbo of the ventral valve. The free edges of the spondylium are almost straight (Pl. VIII, fig. 8) and remain approximately in the plane of junction of the valves.

A thin, median septum is present supporting the spondylium for about half its length (text-fig. 19, transfers 3 to 15; cf. text-fig. 18). It breaks away rather suddenly about 2 mm below the umbo and does not appear to continue as a ridge down the interior of the valve-wall. The septum may be seen to be duplex where it separates from the wall of the valve; but anteriorly this duplex character is lost.

In the dorsal valve the cardinalia consist of a pair of divergent, crural-plates from the ends of which the brachial-processes continue anteriorly (Pl. VIII, fig. 9; text-figs. 18, 19, transfers 7 to 17). The crural-plates show no very distinct division into inner-plates, brachial-processes and outer-plates, but a study of transfers such as text-fig. 19, transfer 13, and of thin-sections (text-fig. 18), suggests that that part of each crural-plate lying ventrally to the base of the brachial-process corresponds to the inner-plate in the cardinalia in other Pentamerids and that the part between the base of the brachial-process and the valve-wall similarly corresponds to the outer-plate. This is supported by the occasional presence, in thin-sections, along the supposed line

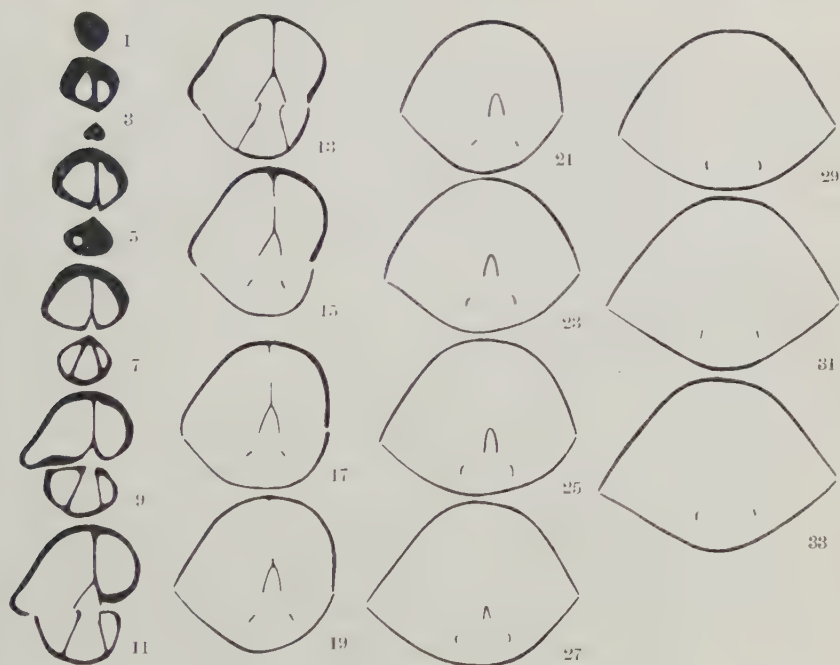
Dimensions of Typical Specimens
(in millimetres).

Length	Breadth	Thickness
9.1	11.5	6.4 (Holotype)
8.6	12.4	6.4 (Paratype)
10.7	12.9	8.1 "
10.0	13.7	9.3 "
9.5	12.7	6.9 "
9.3	11.6	7.6 "
8.2	11.8	7.2 "
9.6	12.8	8.5 "
9.3	12.1	7.6 "
8.8	10.5	6.5 "

of junction of the inner-plates and the bases of the brachial-processes of a small carina pointing ventrally (text-fig. 18); a feature similar to that recorded by Kozłowski (1929, p. 137, fig. 40) in *C. pseudolin-guifera*. The lamellar brachial-processes diverge slowly (Pl. VIII, fig. 9) and frequently continue beyond the end of the spondylium (text-fig. 19, transfers 15 to 33).

Description of Holotype: The holotype (Pl. VII, figs. 7, 10; text-fig. 17, I), is a specimen of average size with a prominent, ventral umbo. The ventral valve is somewhat more convex than the dorsal. The hinge-line is only a little shorter than the maximum breadth. In the ventral valve the median sinus is scarcely developed, while six low plications occur round the anterior margin.

Remarks: *C. malmøyensis* most closely resembles *C. kjerulfi* (Kiær), described above, but it may be distinguished from this species externally by its more transverse shell, and almost straight hinge-line, and internally by its smaller delthyrium and narrower spondylium with a longer supporting septum (contrast text-figs. 13 and 19). In the dorsal valve of *C. malmøyensis* the cardinalia are more strongly divergent than in the second species, while the brachial-processes appear to be rather longer. The carina at the junction of the inner-plates and the bases of the brachial-processes has not been seen in *C. kjerulfi*. *C. malmøyensis* has in common with the earlier species *C. undata*, a transverse outline and long, straight hinge-line; it usually possesses a relatively longer septum than the latter, besides differing externally in its much smaller size and costate shell.



Text-fig. 19. *Clorinda malmøyensis* new species.

Serial transfers (S. M. C. A. 13 515) at 0.10 mm intervals from the posterior end of a specimen; zone 8c, Malmøy. $\times 3$. Transfers 1—33. (Cf. Pl. VIII, figs. 8—9.)

The possession of a costate shell separates *C. malmøyensis* and *C. kjerulfi* from all other species of this genus. It is a feature which appears occasionally in some Pentamerid genera of which the majority of species are smooth. Thus, while most species of the closely allied genus *Barrandella* are smooth, *B. ventricosa* is costate and generally similar externally to the species under consideration. Costation is a somewhat variable character even within a species, and is often absent on young specimens, being attained only in the later stages of growth. Thus, a number of small specimens (P. M. O. 21 350—52) about 4 to 5 mm in length, collected by Kiær probably from horizon 8a at Malmøy, and which have the internal structure of a *Clorinda* are considered provisionally to be young individuals of *C. malmøyensis* although they possess a much more rounded outline, while costation is hardly developed.

Family *Stricklandiidae*.

Genus *Stricklandia* E. Billings 1859.

Billings, E., "On some new Genera and Species of Brachiopoda, from the Silurian and Devonian Rocks of Canada", *The Canadian Naturalist and Geologist*, vol. iv, 1859, pp. 132—5, figs. 8—9.

Davidson, T., "British Fossil Brachiopoda", *Palaeontogr. Soc. Lond.* [Monogr.] III, pt. vii, pp. 157—63 (1867); V, pt. ii, pp. 164—6, (1883).

Hall, J. and Clarke, J. M., *Palaeontology of New York*, VIII, pt. ii, 1894, pp. 249—51.

Schuchert, C. and Cooper, G. A., "Brachiopod Genera of the Suborders Orthoidea and Pentameroidea", *Mem. Peabody Museum nat. Hist. Yale*, IV, pt. i, 1932, pp. 186—8.

Synonym: *Stricklandinia* Billings, E., "On the genus *Stricklandia*; — proposed alteration of the name"; *The Canadian Naturalist and Geologist*, vol. viii, 1863, p. 370.

Genolectotype: *Stricklandia gaspéensis* E. Billings, *The Canadian Naturalist and Geologist*, iv, 1859, p. 134. (Chosen by Hall and Clarke, *op. cit. supra*, p. 250.) Original from Gaspé peninsula, Quebec; horizon Upper Silurian.

Generic description: Transversely-oval to elongate-oval, large Pentameracea, with a straight hinge-line and rather flattened, biconvex profile; valves sub-equal, the dorsal valve frequently with the greater convexity. A small, median fold and sinus often developed. Delthyrium open. Cardinal-areas usually present; that in the ventral valve broad and curved; in the dorsal valve small or linear. Surface of the valves smooth or costate. Shell substance fibrous.

In the ventral valve a very small, dorsally curving spondylium supported on a short, duplex septum. Ovarian markings may be prominent on the posterior part of the inner valve-surface. In the dorsal valve the cardinalia consist of simple, slender brachial-processes and short strongly divergent, inner-plates. Dentition simple; articulation takes place between the thickened, antero-dorsal corners of the delthyrium and the margins of the inner-plates, where these join the valve-wall. Elongate muscle-scars, situated posteriorly, are often prominent.

European species:

Atrypa lens J. de C. Sowerby 1839.

Spirifer liratus J. de C. Sowerby 1839.

[?] *Pentamerus microcamerus* F. McCoy 1851 (? synonym of *S. lens*).

Discussion: *Stricklandia* is most readily recognized by its straight and often long, hinge-line, its low umbones and curved area. Internally, the form of the cardinalia is characteristic. This genus has, in the past, sometimes been regarded as a rather anomalous member of the Pentameracea, distinctly separated from the family Pentameridae (Schuchert and Cooper, 1932, p. 188). Study of the abundant material preserved in this collection suggests, however, that the relationship between *Stricklandia* and *Pentamerus* may be closer than has been imagined. The development of the cardinalia in the former genus, which has hitherto been considered quite distinct from anything represented in the same Super-family, seems on close examination to correspond to the general Pentamerid plan. The resemblance is closest, among known forms, to the cardinalia in *Holorhynchus*, and it would appear that the inner-plates in *Stricklandia* are homologous with the inner-plates of normal Pentamerids. Similarly, the relatively long hinge-line and the very short septum and spondylium are not characters which involve a distinct separation of the genus, for even in this collection both features are present in such species of *Clorinda* as *C. undata* and *C. malmøyensis*.

Stricklandia lens (J. de C. Sowerby) 1839.

Plates III, figs. 1—3, 7—9, 12—17; VI, figs. 12, 14; VIII, figs. 10—19;
Text-figs. 20—22.

1839. *Atrypa lens* Sowerby, J. de C., in Murchison's "Silurian System", p. 637, pl. 21, fig. 3.

1867. *Stricklandinia lens* (J. de C. Sow.). Davidson, T., "British Fossil Brachiopoda", *Palaeontogr. Soc. Lond. [Monogr.]*, III, pt. vii, pp. 161—3, pl. xix, figs. 13—23 (with Bibliography). *Idem*, V, pt. ii, 1883, p. 165, pl. ix, figs. 2—5.

1908. *Stricklandinia lens* (J. de C. Sow.). Kiær, J., "Das Obersilur im Kristianiagebiete", *Vidensk. Selsk. Skrifter, Math.-Naturv. Kl.* (1906), II, *passim*.

[?] Synonym: *Pentamerus microcamerus* McCoy, F., *Ann. Mag. nat. Hist.*, 2nd Series, vol. viii, 1851, pp. 390—1, reprinted in Sedgwick and McCoy "British Palaeozoic Rocks and Fossils", 1851—5, p. 210 (1852).

Material: P. M. O. specimens 21138—72, —74—99, 21201—02, —71, 40420—22, —93—95, 40555—62, 41375—76, —80—82, 41977—42031, —34—36, —69—77, 42087—101, 42103, —05, 52388—89, —91—99, 52401, —03, —08—11, —13—14, —16, —19—21, —23—28, —30—55, 52599, 52601—02, —05, —08,

—19, 52730—45, 52828—39, 53199—202, 53265, —68—96, 53315—16, 53436—42, 54580—85, —94, 54605—09, 58354—69, 58525—49.

Syntypes: The two specimens figured by J. de C. Sowerby *op. cit.*, 1839, pl. 21, fig. 3. These are preserved in the Collection of the Geological Survey, London [No. 6905 (upper figure), from the Upper Llandovery of Mandinam, Carmarthenshire; No. 6678 (lower figure), from the Lower Llandovery of Cefn Rhyddan, S. E. of Llandovery, Carmarthenshire]. Cf. Pl. VI, figs. 14 and 12.

Diagnosis: Large, smooth *Stricklandia* usually sub-circular to elongate-oval in outline. Hinge-line straight, rather long. Valves about equi-convex, umbones low, approximate (Pl. III). A small cardinal-area in the ventral valve. Often a long, fan-shaped, median, dorsal fold which may cause a slight plication of the anterior margin. In the ventral valve an open delthyrium and small, dorsally-curving, spondylium partly supported on a short, duplex septum. In the dorsal valve slender, lamellar, brachial-processes, which are in contact for about half their length with a pair of divergent inner-plates.

Discussion: A number of different shape-variations are represented among the several hundred individuals of this species (mostly from zone 6c α), that have been examined. The dimensions of length and breadth are commonly about equal giving an approximately sub-circular outline (Pl. III, figs. 1, 3, 12, 15), but some elongate forms occur with the dimension of length exceeding the breadth (Pl. III, fig. 17). Occasionally, as in specimens from 6c α at Malmøy (P. M. O. 21174—8) it is the breadth that is increased, producing a transverse variety. In all these forms the maximum thickness is attained half-way or rather less from the hinge-line, to the anterior margin (Pl. III, figs. 2, 8 and 13). In profile, the valves are gently convex or somewhat flattened. The umbones are usually very small and low, often inconspicuous, rising only slightly above the hinge-line. The latter is always less than the greatest width of the shell, and the valve-margins curve slowly outwards until the maximum breadth is attained.

The surface of the dorsal valve is elevated into a low, median fold that commences a little below the umbo and increases considerably in width towards the anterior, where its sides are rather ill-defined (Pl. III, figs. 7, 12, 15, 17). In specimens in which the fold produces a plication of the margin a shallow sinus may be present in the ventral valve (Pl. III, figs. 3, 16). In a number of individuals

(e. g., P. M. O. 21180, 53268) there are faint traces of secondary folds (costae) on either side of the median fold and sinus. Concentric growth-lines are often prominent towards the anterior margin.

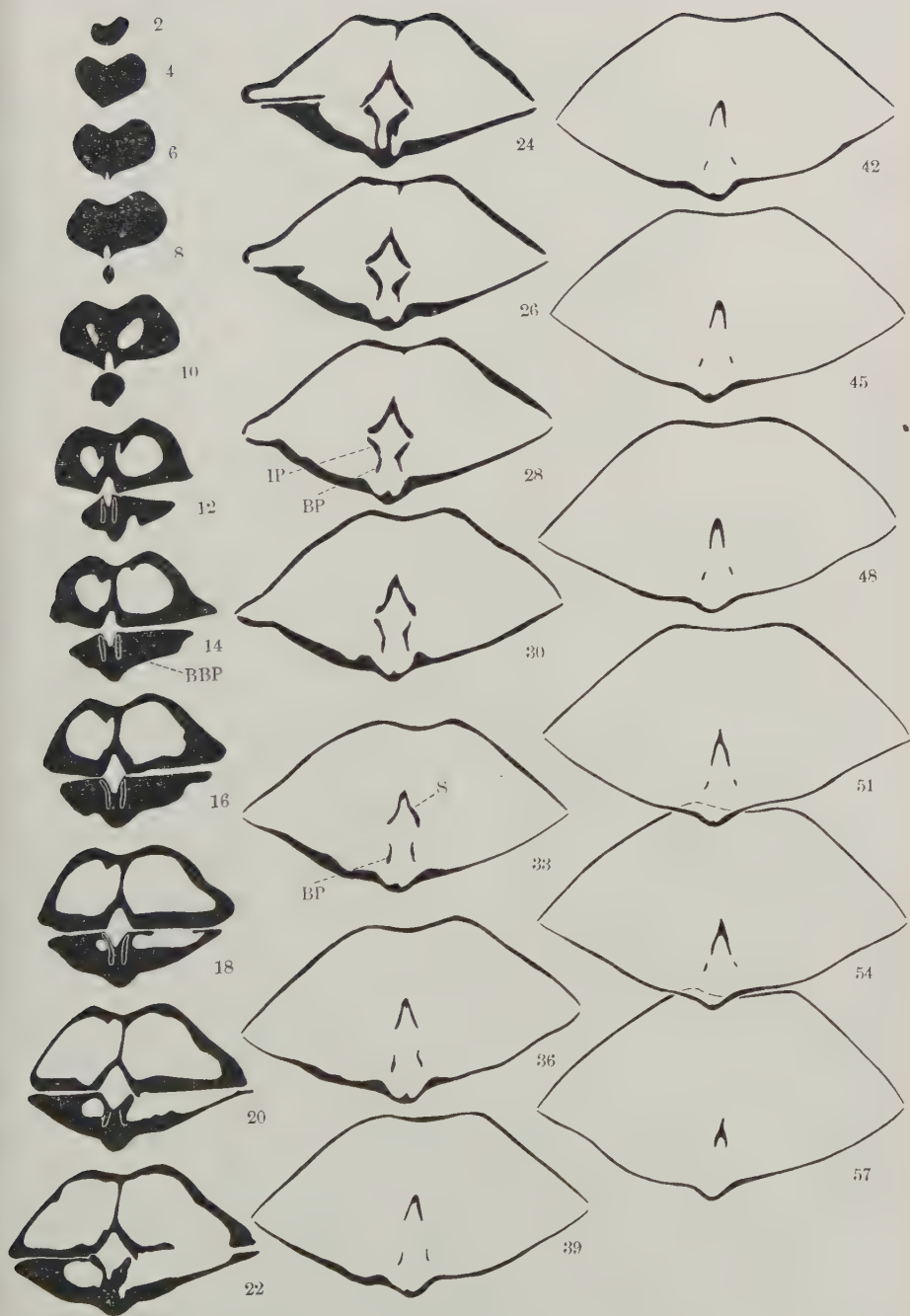
The extensive variation that occurs in this species is of a similar character to that observed in *P. laevis*. It is perhaps best illustrated by a description of a suite of specimens (P. M. O. 58529—49) all from the same horizon and locality (zone 6 c at Malmøy about 30 m thick) specially selected by Kiær to show the variation occurring between forms from different beds of rock. Thus, within this group, P. M. O. 58547—49 probably from the lowest level, are transverse forms, considerably wider than long, with inconspicuous umbones and a hinge-line approaching the greatest breadth of the shell. They possess a rather clearly developed, dorsal, median fold, while a shallow sinus is also present. P. M. O. 58543—46 from the next band, are of about the same average size, but with their dimensions of length and breadth approximately equal, producing a sub-circular outline. Specimens P. M. O. 58539—42 from the succeeding bed are elongated forms with the length considerably greater than the breadth, and with a short hinge-line. The cardinal-angles are rather prominent. The next group, P. M. O. 58534—38 are small and of rounded outline with a distinctly developed, median, dorsal fold. Finally, P. M. O. 58529—33 apparently from the top bed, are similar to the foregoing, but with the median fold forming a prolongation of the anterior margin, while the cardinal-angles again tend to be distinctly marked. All the specimens in this series have very small, inconspicuous umbones, but there is evidently a considerable variation from bed to bed, and similar series could probably be obtained from other districts.

Internal Characters: The delthyrium in this species is usually covered by the incurved dorsal umbo, which fits closely below the apex of the ventral valve when the two valves are in apposition (Pl. VIII, figs. 10, 19). The spondylium is of the short, open type which characterizes *Stricklandia* (Pl. VIII, figs. 12, 15). It usually extends for between one-quarter and one-sixth of the length of the shell, always curving forward towards the cavity of the dorsal valve (text-fig. 20, transfers 24 to 57 and Pl. VIII, figs. 11, 16, 18). 'Teeth' are better developed in this species than in many other Pentamerids. The spondylial walls are often appreciably thickened at the point where they join the hinge-line, and may extend slightly dorsally from the commissure to make contact with the edges of the inner-

plates of the dorsal valve (text-fig. 20, transfers 20 to 24). The median, duplex septum is rather thin and short (text-figs. 20 and 21); in specimens of average size it may extend for 4 or 5 mm anterior to the umbo, supporting the spondylium for less than half the length of the latter (Pl. VIII, figs. 11, 17). The posterior portion of the inner surface of the spondylial cavity is covered by a thin layer of lamellar shell-material (text-fig. 22, where this layer is stippled), apparently of the same nature as that described in species of *Pentamerus*, though it is not so sharply separated from the shell-wall as in that genus. Along the margins of the delthyrium small ridges may occur, slightly constricting the delthyrial opening (text-fig. 22). They are evidently of the same nature as the "incipient deltidial plates" that have been described in certain species of *Clorinda* (Booker, 1927, p. 134). When the valves are in apposition the ridges lie close to the surface of the dorsal valve and fill the narrow gaps between the dorsal umbo and the delthyrial margins. A true pseudo-deltidium has not been observed.

In the dorsal valve the cardinalia consist only of brachial-processes and inner-plates. The bases of the brachial-processes may be traced almost to the umbo, embedded in later deposited shell-substance (text-fig. 20, transfers 12 to 22). They separate from the valve-wall a little anterior to the hinge-line, and continue as flattened rods (Pl. VIII, figs. 13—14; text-figs. 20 and 21, transfers 24 to 54 and 25 to 57 respectively), which may embrace the anterior end of the spondylium when the valves are in the position of life (text-fig. 21, transfers 55 to 57; Pl. VIII, fig. 11). Attached to the ventral edges of the brachial-processes are a pair of divergent inner-plates (Pl. VIII, fig. 13; text-figs. 20 and 21, transfers 24 to 30 and 23 to 33 respectively). These are usually rather wider than the brachial-processes, but extend for only half their length. The junctions of the inner-plates with the hinge-line define two sockets into which there project the 'teeth' of the ventral valve.

Description of Types: Of the two syntypes figured by J. de C. Sowerby, No. 6905 in the Collection of the Geological Survey, London, is an incomplete, internal cast (with counter-part), of an average-sized specimen, with a very short septum in the ventral valve (cf. Pl. VI, fig. 14). A low, median, dorsal fold is present and there are traces of faint, secondary costae on either side. No. 6678 in the same Collection is an internal cast of a ventral valve, with a



Text-fig. 20. *Stricklandia lens* (J. de C. Sowerby).

Serial transfers (S. M. C. A. 13516) at 0.10 mm intervals from the posterior end of a specimen; zone 6 b β , Asker. $\times 2$. Transfers 2—57 (cf. Pl. VIII, fig. 17). BBP=bases of the brachial-processes; BP=brachial-processes; IP=inner-plates; S=spondylium.

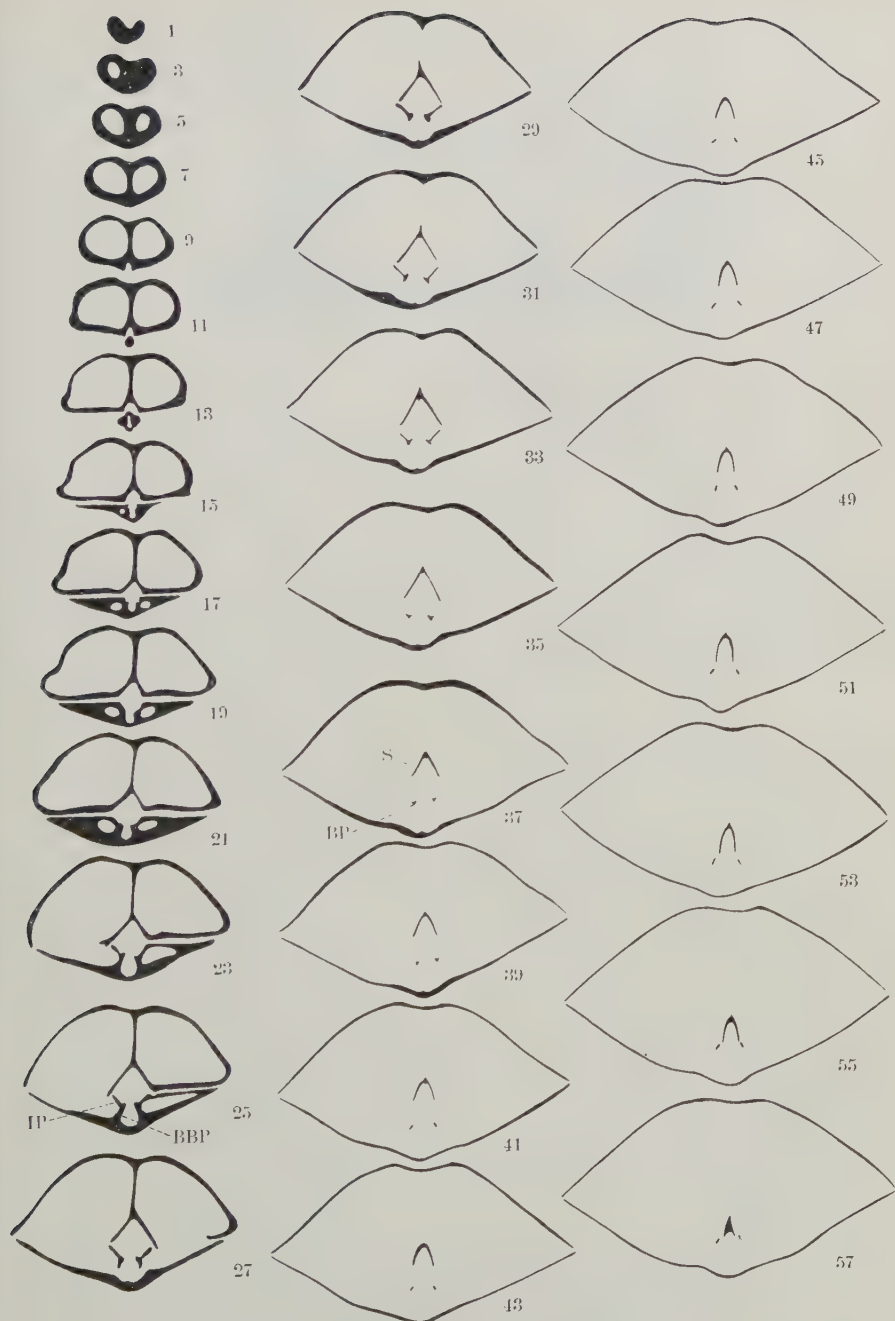
Dimensions of Typical Specimens
(in millimetres).

Length	Breadth	Thickness
c. 49.5	46.0	18.5 (present dimensions
66.0	49.0	-) of types)
67.0	60.0	36.0
62.1	63.2	33.3
60.9	49.2	27.7
56.4	53.4	32.8
29.8	25.0	14.8
28.9	24.5	12.9
44.4	62.2	23.9
51.0	44.0	22.7

short septum (Pl. VI, fig. 12). Very slight, radiating folds and concentric growth-lines occur towards the anterior margin.

Remarks: In spite of its many shape-variations *S. lens* may be easily identified by its essentially lenticular profile, smooth shell, poorly developed fold and sinus and small incurved umbones. The slight plications that have been described as occurring round the anterior margins in some specimens never approach the size or prominence of the costae of a typical *S. lirata*.

S. lens is extremely common at horizon 6 c of the Norwegian Silurian being especially characteristic of the eastern development. There, at Malmøy and Asker, it may attain importance as a rock former (Kiær, 1908, pp. 142—3, 340—1). The earliest appearance of the species is at Asker, where in 6 b β there occurs a small variety (Kiær, *op. cit.*, p. 326) often somewhat triangular in outline. It is the zone-fossil for horizon 6 c α in which it attains its maximum abundance, and most of the material in the Collection has come from the Malmøy and Asker districts at this horizon. The main variations at Malmøy have been described, and similar types occur in the Asker region. Kiær (*op. cit.*, p. 193) records that it is common also at Holmestrand in 6 c α . In the western development, as at Ringerike and Skien and Porsgrund, the species is almost entirely absent. In 6 c β it is still present in the eastern areas, though much less common; it overlaps in this zone (at Asker) with the oldest member of the *Pentamerus* series (Kiær, *op. cit.*, pp. 342, 499). Rare examples are also found at horizon 7 a at Malmøy, Asker and Holmestrand (Kiær, pp. 153, 351, 199—200).



Text-fig. 21. *Stricklandia lens* (J. de C. Sowerby).

Serial transfers (S. M. C. A. 13518) at 0.125 mm intervals from the posterior end of a specimen; zone 6 c α , Malmøy. $\times 1\frac{1}{3}$. Transfers 1–57 (cf. Pl. VIII, figs. 12–13). BBP = bases of the brachial-processes; BP = brachial-processes; IP = inner-plates; S = spondylium.



Text-fig. 22. *Stricklandia lens* (J. de C. Sowerby).

Transfer from the posterior end of a specimen, S. M. C. A. 13 519 (18). $\times 5$.

S. lens does not appear to have been recorded from the Baltic Provinces, but in England it is very common, appearing first at the top of the Lower Llandovery, reaching its maximum in the Middle Llandovery, and extending also to the Upper Llandovery.

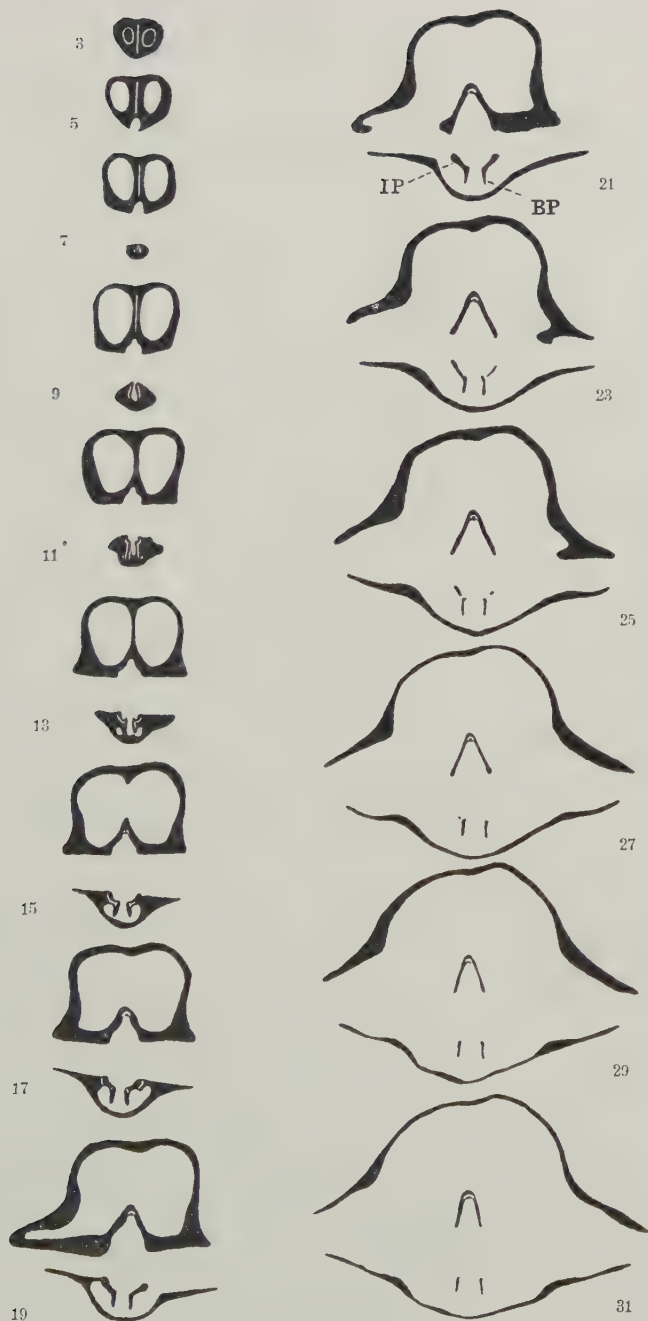
Stricklandia lirata (J. de C. Sowerby) 1839.

Text-figs. 2, vii and 23.

1839. *Spirifer liratus* Sowerby, J. de C., in Murchison's "Silurian System", p. 638, pl. 22, fig. 6.
1867. *Stricklandinia lirata* (J. de C. Sow.). Davidson, T., "British Fossil Brachiopoda", *Palaeontogr. Soc. Lond. [Monogr.]*, III, pt. vii, pp. 159—61, pl. xx, figs. 1—13. *Idem*, V, pt. ii (1883), p. 165, pl. ix, fig. 1.
1908. *Stricklandinia lirata* (J. de C. Sow.). Kiær, J., "Das Obersilur im Kristianiagebiete", *Vidensk. Selsk. Skrifter, Math.-Naturv. Kl.* (1906), II, *passim*.
1935. *Stricklandia lirata* (J. de C. Sow.). St. Joseph, J. K. S., "A Critical Examination of *Stricklandia lirata* (J. de C. Sowerby) 1839", *Geol. Mag. Lond.*, LXXII, pp. 401—24, pls. xvi—xvii (with full Bibliography).

Synonyms: *Cardium multisulcatum* Hisinger, W., *Lethaea Svecica, supplementi secundi continuatio*, 1841, p. 4, pl. xli, figs. 3 a—b.
Spirifer ovatus McCoy, F., A. Synopsis of the Silurian Fossils of Ireland (1846), 1862, p. 37, pl. iii, fig. 24.

Material: P. M. O. specimens 21 664—73, 45 439—40, —68—71, —74—75, —77, 45 515—16, —94—96.



. Text-fig. 23. *Stricklandia lirata* (J. de C. Sowerby).

Serial transfers (S. M. C. A. 7039) at 0.15 mm intervals from the posterior end of a specimen; zone 7 c β , Ringerike. $\times 2$ approx. (For the complete series, see St. Joseph 1935 b, pp. 407—9, text-fig. 2.). BP = brachial-processes; IP = inner-plates.

Holotype: Specimen 6618 in the Collection of the Geological Survey, London, from the top of the Llandovery at Marloes Bay, Pembrokeshire; figured by J. de C. Sowerby *op. cit.*, 1839, pl. 22, fig. 6.

The account of this species is condensed from St. Joseph, *op. cit. supra*, 1935. All the specimens of *S. lirata* in the Kiær Collection are of the forma *typica*.

Diagnosis¹: Large, sub-circular to oval *Stricklandia*, the valves nearly equal, the ventral a little larger than the dorsal. Maximum breadth usually rather greater than the length. Hinge-line straight, somewhat less than the greatest breadth of the shell. Umbones approximate, the ventral slightly the higher. Ventral cardinal-area small, curved. Often a low, prominent, median fold in the dorsal valve, and corresponding sinus in the ventral. Valves multicostate. In the ventral valve a typical, small, open spondylium and duplex septum. In the dorsal valve the cardinalia consist of small inner-plates² and slender, parallel, brachial-processes (crural-processes).

Discussion: The variation in external characters exhibited by this species has recently been discussed with particular reference to British material (St. Joseph, 1935 b, pp. 403—4, 418—21) and only special characteristics of the Norwegian specimens will be noted here. The Kiær Collection includes a few large individuals (P. M. O. 21664—6, 45594—6) identical with the forma *typica*, and also smaller specimens (P. M. O. 21667, 21671) with a somewhat more convex ventral valve and slightly less prominent ribbing — a variation which is not very common in Britain. The umbones are sometimes a little incurved and there is a small, sloping cardinal-area on the ventral valve. The sinus is always developed, but the dorsal fold may be ill-defined, or present only at the anterior margin.

Internal Characters: The delthyrium appears to have been open as the dorsal umbo seldom curves far forward from the plane of junction of the valves, while in the few specimens in which the feature can be studied, no structures constricting the delthyrial opening have been seen. The spondylium is short compared with the length of the shell, it is free for the greater part of its length, the supporting

¹ This diagnosis applies particularly to *S. lirata* forma *typica*.

² These were termed previously 'outer plates' (St. Joseph, 1935 b, p. 413), referring to their lateral position relative to the brachial-processes. The nomenclature is now altered to 'inner-plates', in order that the terminology may agree with that in use for other Pentamerids.

septum being very small (text-fig. 23). The low, median ridge at the back of the spondylial cavity is often distinct; it probably separated muscle impressions. The duplex character of the septum is generally well marked, and the median plane of separation may be traced right to the posterior end of the valve. The extensive, secondary thickening of the posterior portion of the shell that has been described in specimens of the forma *typica* from England has not been observed in the Norwegian material.

In the dorsal valve the cardinalia consist of rather slender, lamellar, brachial-processes and strongly divergent inner-plates (text-fig. 23, transfers 15—31). The former are approximately parallel and situated close to the valve-wall, they extend for about the same distance as the spondylium. The inner-plates are seen from sections to be quite distinct structurally from the brachial-processes of which they attain about half the length. The two may remain in contact, or separate slightly towards the anterior (text-fig. 23, transfers 19 to 27). The bases of the brachial-processes appear to be attached directly to the valve-wall, as if no structure were present, corresponding to the outer-plates of *Pentamerus*.

Remarks: The species may easily be distinguished from *Stricklandia lens*, the only other Norwegian form referred to this genus, by its strongly costate shell, and much more prominent umbones.

All the specimens of *S. lirata* in the Collection have come from Ringerike at horizon 7 c β , of which it is characteristic, Kiær (1906, p. 64) choosing it as the zone fossil. It is common at that horizon, occurring together with *P. cf. gotlandicus*. The material consists for the greater part, of isolated valves, and adds little to the knowledge of the internal structure of the species. *S. lirata* is also recorded from Skien and Porsgrund (*op. cit.*, p. 273) and occasionally from Holmestrand (p. 207) and Asker (pp. 356—7), where the faunal development closely parallels that at Ringerike. It is absent in the eastern districts (Malmøy). Kiær reported rare examples of the species from the Wenlock horizon 8 b, in the western area (*op. cit.*, pp. 74—5, and 279), though none of these are contained in the Collection. It seems doubtful whether they are really typical specimens. *S. lirata* forma *typica* occurs also in Gotland, being common in the lower part of the Wisby group, and in England where it characterizes a narrow horizon at the junction of the Llandovery and Wenlock beds.

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¹ For this date cf. Bather, F. A., *K. svenska Vetensk. Akad. Handl.*, Band 25 No. 2 (1893), p. 10.

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PLATES

PLATES I—III ARE FROM FIGURES
PREPARED BY KIÆR

Plate I.

Pentamerus borealis (C. E. Eichwald).

All figures natural size.

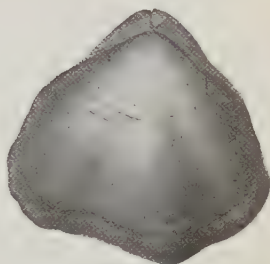
- Figs. 1—2. Ventral and right-lateral views of specimen P. M. O. 54 726. Zone 7 a, Bjerkøy, Holmestrand.
- » 3. Dorsal view of specimen P. M. O. 54 834. Zone 7a, Bjerkøy, Holmestrand.
- » 4—6. Dorsal, left-lateral and ventral views of specimen P. M. O. 58 553. Zone 7a, Ringerike.
- » 7—9. Dorsal, left-lateral and ventral views of a specimen. Zone 7a, Bjerkøy. Original unidentified.



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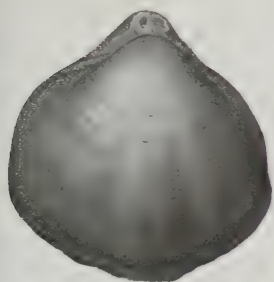
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Plate II

Pentamerus laevis J. Sowerby.

All figures natural size.

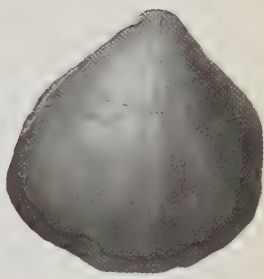
- Figs. 1—3. Dorsal, right-lateral and ventral views of a rather trilobed specimen. Zone 7 b, Malmøykalv. Original unidentified.
- * 4—6. Dorsal, left-lateral and ventral views of a broad specimen, P. M. O. 42 639. Zone 7 a (?), Malmøy.
- * 7—9. Dorsal, right-lateral and ventral views of a young specimen. Zone 7 b, Malmøykalv. Original unidentified.
- * 10—12. Dorsal, right-lateral and ventral views of a young specimen, P. M. O. 40 523. Zone 7 a Malmøy.
- * 13—15. Dorsal, right-lateral and ventral views of a young specimen, P. M. O. 40 514 a. Zone 7 b β , Malmøy.
- * 16—18. Dorsal, right-lateral and ventral views of specimen P. M. O. 40 520. Zone 7 a (top), Malmøy.



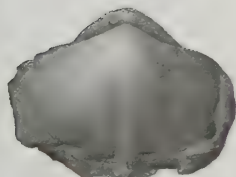
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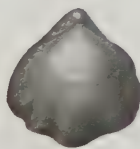
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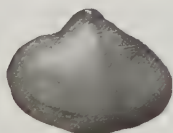
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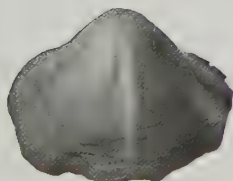
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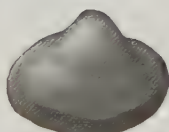
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Plate III

All figures natural size.

Stricklandia lens (J. de C. Sowerby).

- Figs. 1—3. Dorsal, left-lateral and ventral views of specimen P. M. O. 41 376. Zone 6 c, Malmøy.
- » 7—9. Dorsal, left-lateral and ventral views of a specimen. Zone 6 (top), Asker. Original unidentified.
- » 12—14. Dorsal, left-lateral and ventral views of a young specimen, P. M. O. 54 594 a. Zone 6 c, Bjerkøy.
- » 15—16. Dorsal and ventral views of a specimen. Zone 6—7, Asker. Original unidentified.
- » 17. Dorsal view of a specimen. Zone 6 c, Malmøy. Original unidentified.

Pentamerus laevis J. Sowerby.

- » 4—6. Dorsal, left-lateral and ventral views of a specimen. Zone 7 a (?), Malmøy. Original unidentified.
- » 10—11. Dorsal and right-lateral views of a specimen. Zone 7 b (?). Original unidentified.

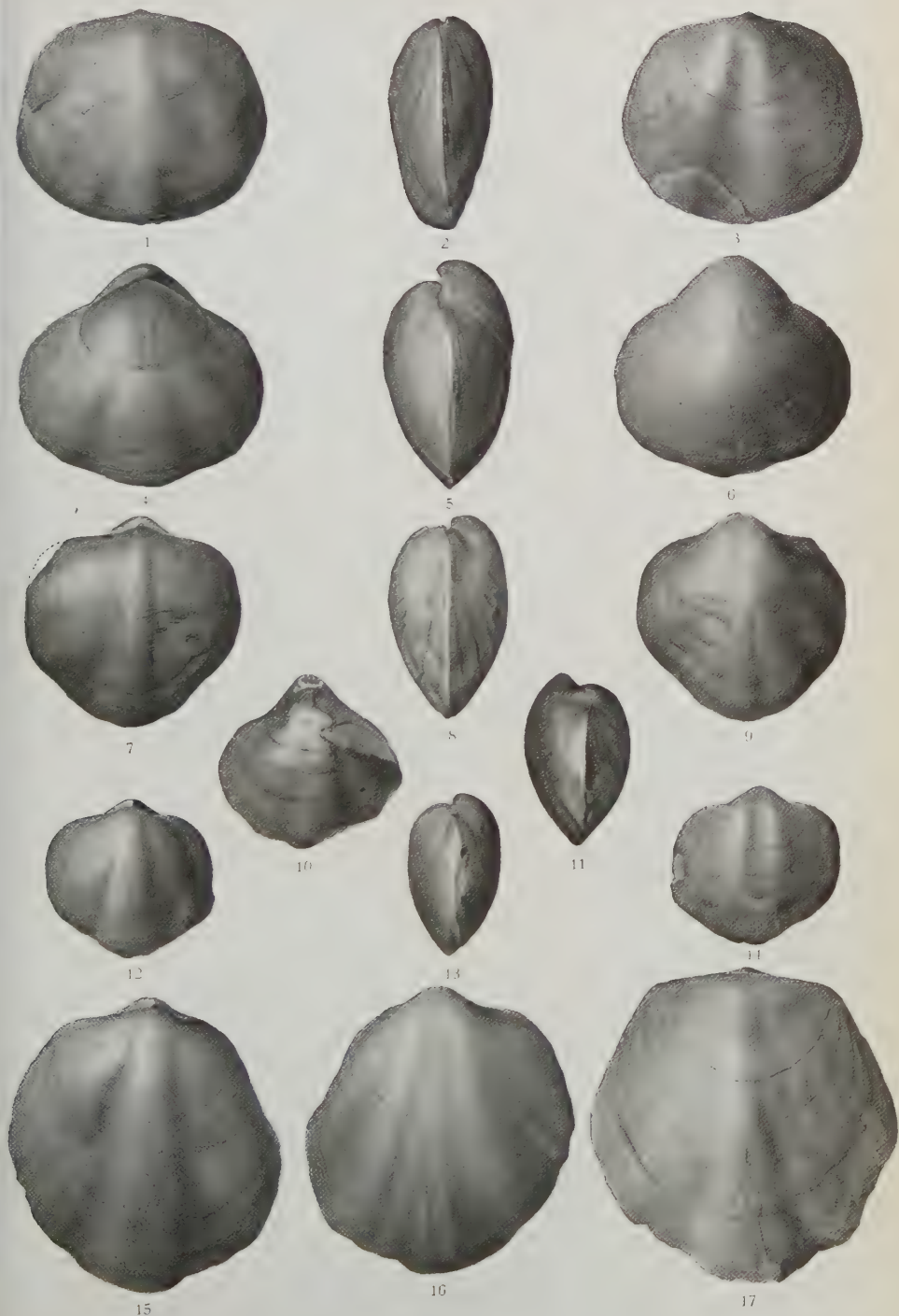
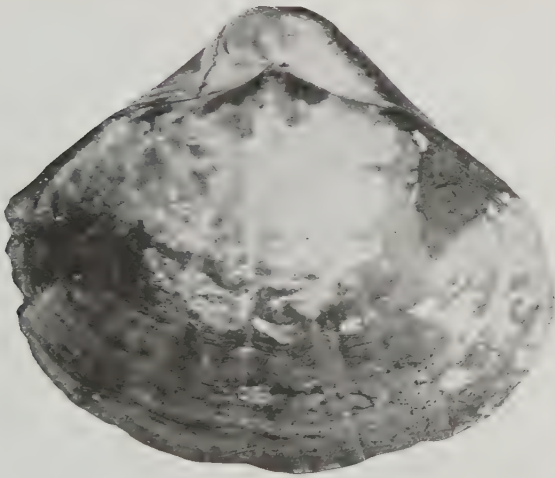


Plate IV

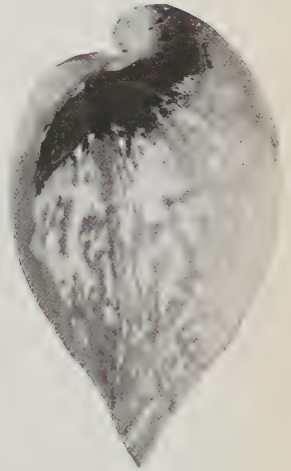
Holorhynchus giganteus J. Kiær.

All figures natural size.

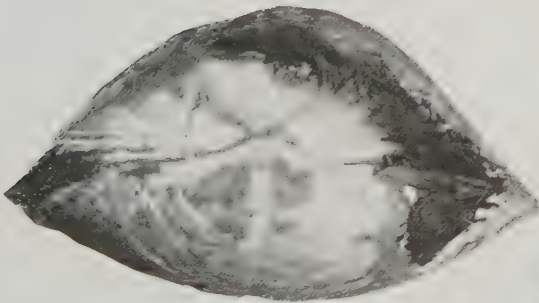
- Figs. 1—3. Dorsal, left-lateral and posterior views of the lectotype. P. M. O. 12431. Zone 5 b, Aspelund, Asker.
- » 4—5. Dorsal and left-lateral views of specimen P. M. O. 12491. Zone 5 b, Asker. This specimen has been destroyed in obtaining the series of transfers shown in text-fig. 9.



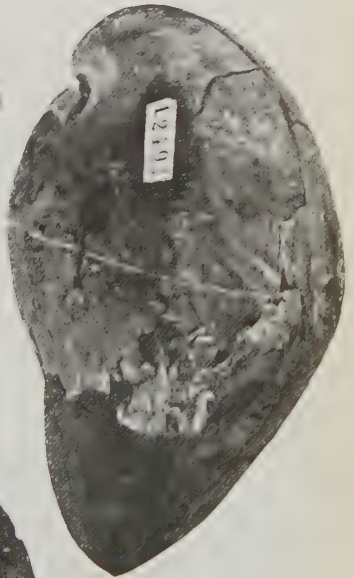
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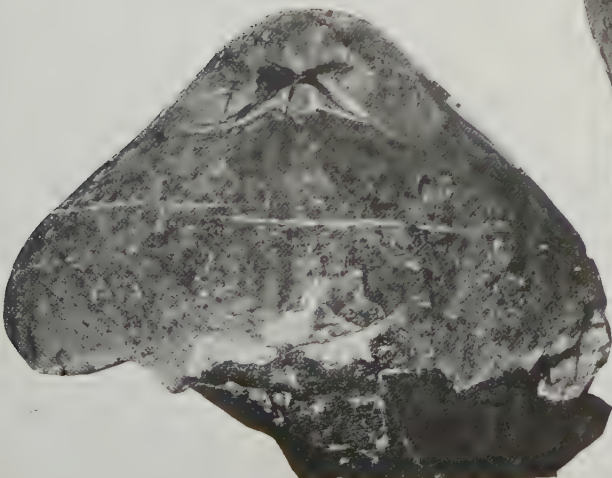
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Plate V

Wax models, constructed from serial transfers, of the posterior portions of the shells of various Norwegian Pentamerids.

Pentamerus borealis (C. E. Eichwald).

- Fig. 1. Antero-lateral aspect, showing the spondylium, which is free for the lower half of its length, curving dorsally towards the cardinalia. $\times 1\frac{1}{4}$. S. M. C. A. 13 502; original from zone 7 a, Ringerike. Compare text-fig. 3.
- » 2. Ventro-lateral aspect of the dorsal valve of the same specimen. $\times 1\frac{1}{4}$.
- » 3. Dorso-lateral aspect of the ventral valve of the same specimen, showing the shape of the spondylium. $\times 1\frac{1}{4}$.
- » 4. Dorsal aspect of a ventral valve of a young specimen. $\times 2$. S. M. C. A. 13 501; original from zone 7 a, Ringerike.

Pentamerus laevis J. Sowerby.

- » 5. Ventral aspect of a dorsal valve of a rather young specimen. $\times 2\frac{1}{2}$. S. M. C. A. 13 504; original from zone 7 b β , Malmøy. Compare text-fig. 6.
- » 6. Dorsal aspect of the ventral valve of the same specimen. A small pseudodeltidium is present at the apex of the delthyrium. $\times 2\frac{1}{2}$.
- » 10. Antero-lateral aspect, showing the relative positions of the cardinalia and the spondylium. The latter is supported on a median septum for the greater part of its length. $\times 1\frac{1}{2}$. S. M. C. A. 13 503; original from zone 7 b, Malmøy. Cf. text-fig. 5.

Pentamerus (*Pentameroides*) cf. *gotlandicus* N. Lebedev.

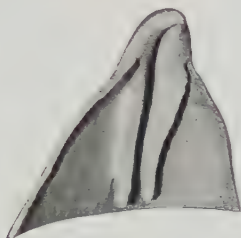
- » 7. Dorsal aspect of a ventral valve, showing the narrow spondylium supported on a long, median septum. A concave pseudodeltidium covers the apex of the delthyrium. Natural size. S. M. C. A. 13 507; original from zone 7 c β , Ringerike. Compare text-fig. 8.
- » 8. Ventral aspect of the dorsal valve of the same specimen, showing the long cruralium. Natural size.

Conchidium münsteri new species.

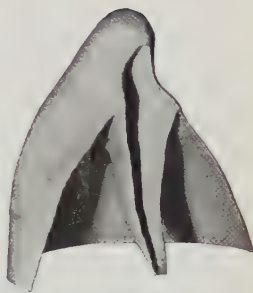
- » 9 & 11. Dorsal and dorso-lateral aspects of a ventral valve, with a large delthyrium and spondylium and long median septum. $\times 2$. S. M. C. A. 13 509; original from zone 5 b, Ringerike. Cf. text-fig. 10. Topotype.



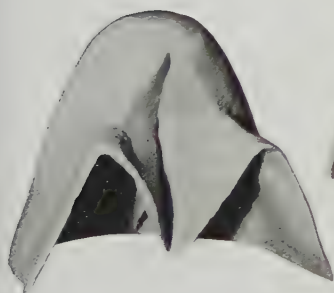
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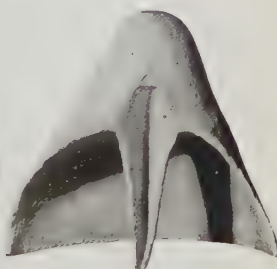
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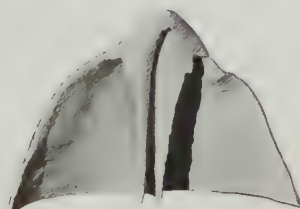
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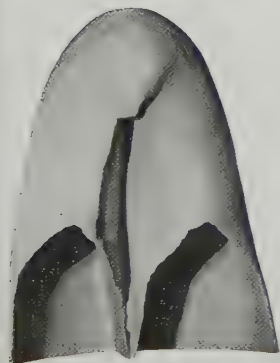
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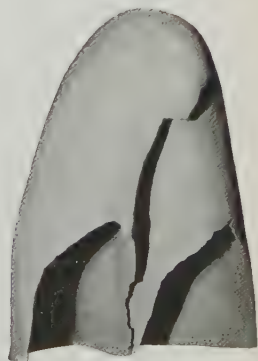
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Plate VI

Figures natural size, unless otherwise stated.

Clorinda undata (J. de C. Sowerby).

- Figs. 1—3. Dorsal, right-lateral and anterior views of specimen P. M. O. 52 136. Zone 6 a, Asker.
- » 4 & 8. Dorsal and anterior views of specimen P. M. O. 41 262. Zone 6 b—c, Ulvøy.
 - » 5—6. Right-lateral and anterior views of specimen P. M. O. 42 491. Zone 6 c β , Malmøy.
 - » 7. Syntype: an internal cast viewed from the dorsal side. Geological Survey, London 7612. Lower Llandovery, Cefn-y-garreg, Carmarthenshire.
 - » 9. Right-lateral view of specimen P. M. O. 53 714. Zone 7 b, Barüm.

Conchidium münsteri new species [Kiær MS.].

- » 10. The two paratypes: from left to right P. M. O. 20 821 b and c, respectively. Zone 5 b, Vestre Svartøy, Ringerike.
- » 11. Left-lateral view of the holotype. P. M. O. 20 821 a. Zone 5 b, Vestre Svartøy, Ringerike.

Stricklandia lens (J. de C. Sowerby).

- » 12. Ventral view of syntype 2, $\times \frac{3}{4}$. Geological Survey, London 6678, from the Lower Llandovery (top part), Carmarthenshire. Cf. J. de C. Sowerby, 1839, pl. 21, fig. 3, bottom figure.
- » 14. Dorsal view of syntype 1. Geological Survey, London 6905, from the Upper Llandovery, Carmarthenshire. Cf. J. de C. Sowerby, 1839, pl. 21, fig. 3, top figure.

Pentamerus (Pentameroides) cf. gotlandicus N. Lebedev.

- » 13 & 15. Right-lateral and dorsal views of a small specimen, P. M. O. 58 562. Zone 7 c β , Ringerike.

Pentamerus laevis J. Sowerby.

- » 16 & 17. Right-lateral and dorsal views of a plesiotype. Geological Survey, London 6908. Upper Llandovery, Salop (?), England. Figured by J. de C. Sowerby (1839, pl. 19, fig. 10) as a syntype of "*Pentamerus oblongus*"

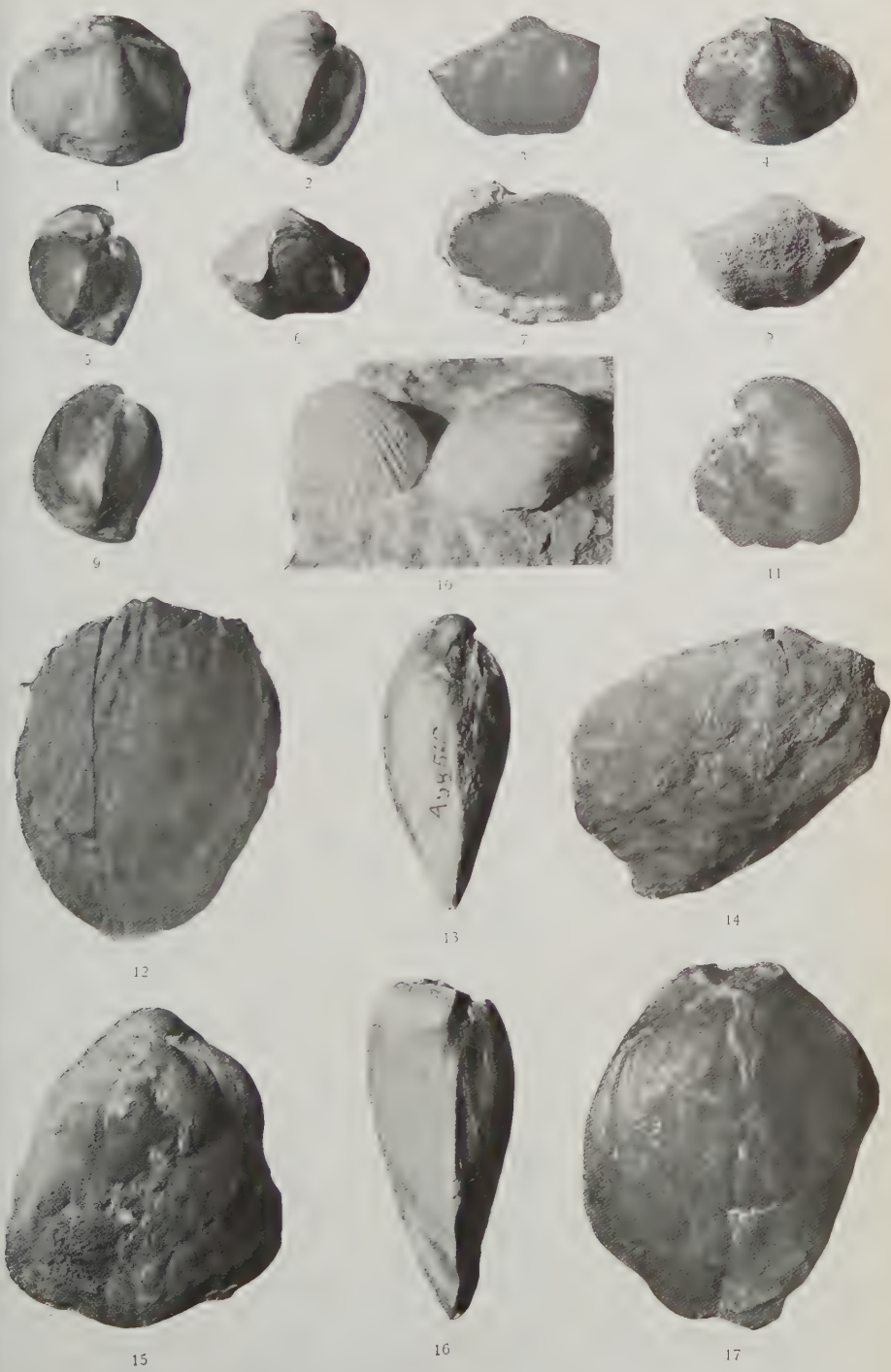


Plate VII

All figures twice natural size.

Clorinda kjerulfi (J. Kiær).

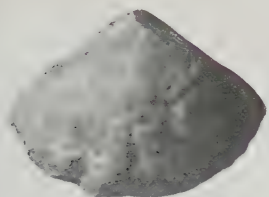
- Figs. 1 & 4. Dorsal and right-lateral views of the lectotype, P. M. O. 12 598. Zone 5 b, Halden, Asker.
- » 2 & 5. Dorsal and right-lateral views of paratype, P. M. O. 12 595. Zone 5 b, Halden, Asker.
- » 3 & 6. Dorsal and right-lateral views of paratype, P. M. O. 40 466. Zone 5 b, Jørgensløggen, Asker.

Clorinda malmøensis new species.

- » 7 & 10. Dorsal and right-lateral views of the holotype, P. M. O. 21 389 a. Zone 8 c (lower part), Malmøy.
- » 8 & 11. Dorsal right-lateral views of paratype, P. M. O. 21 389 b. Same horizon and locality.
- » 9 & 12. Dorsal and right-lateral views of paratype, P. M. O. 21 389 c. Same horizon and locality.

Clorinda undata (J. de C. Sowerby).

- » 13—15. Dorsal, right-lateral and anterior views of specimen P. M. O. 20 863 a. Zone 6 b, Sjursøy, Oslo.



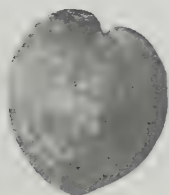
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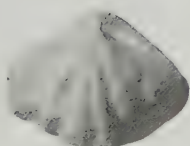
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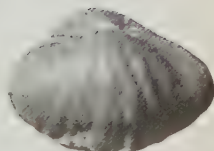
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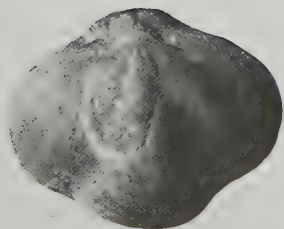
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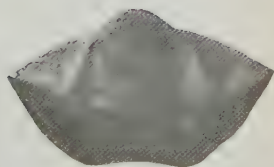
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Plate VIII

Wax models, constructed from serial transfers, of the posterior portions of the shells of various Norwegian Pentamerids.

Clorinda kjerulfi (J. Kiær).

- Figs. 1—2. Dorsal and dorso-lateral aspects of a ventral valve, showing the short, wide spondylium. Fig. 1 $\times 2\frac{1}{2}$; fig. 2 $\times 3$. S. M. C. A. 13 510; original from zone 5 b, Asker. Cf. text-fig. 13. Topotype.
- » 3. Ventral aspect of the dorsal valve of the same specimen, showing the brachial-processes and inner-plates. $\times 2\frac{1}{2}$.

Clorinda undata (J. de C. Sowerby).

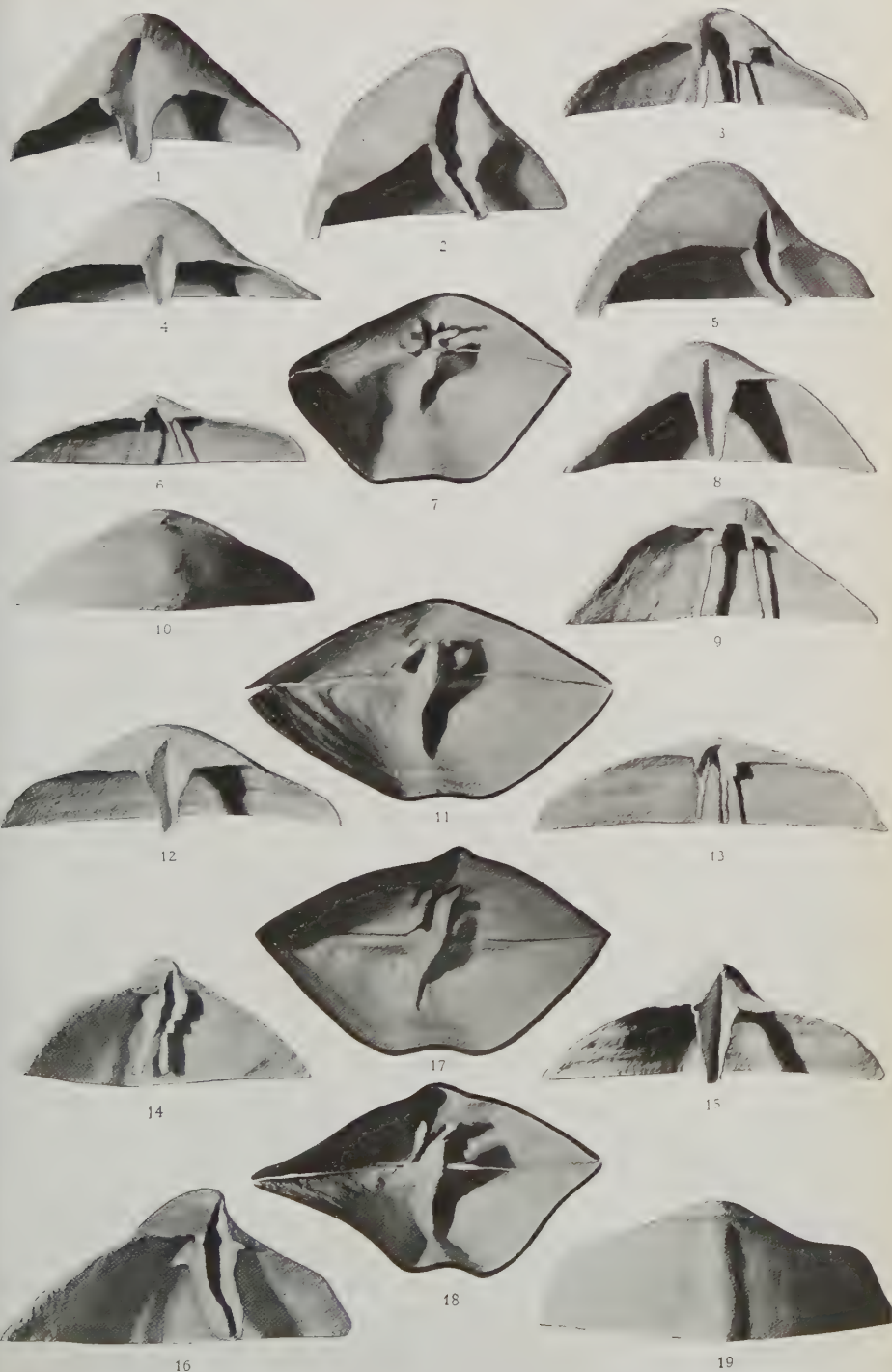
- » 4—5. Dorsal and dorso-lateral aspects of a ventral valve. The short spondylium curves dorsally from the commissure. Fig. 3 $\times 3$; fig. 5 $\times 2$. S. M. C. A. 13 512; original from zone 6 a β , Sjørø, Oslo. Compare text-fig. 14.
- » 6. Ventral aspect of the dorsal valve of the same specimen, showing the slender brachial-processes. $\times 2$.
- » 7. Antero-lateral aspect of the same specimen. The brachial-processes separate the divergent outer-plates (near the wall of the dorsal valve) from the inner-plates (near the spondylium). $\times 2$. Compare text-fig. 14.

Clorinda malmøensis new species.

- » 8. Dorsal aspect of a ventral valve. $\times 4$. S. M. C. A. 13 515; original from zone 6 c (lower part), Malmøy. Compare text-fig. 19. Paratype.
- » 9. Ventral aspect of the dorsal valve of the same specimen. $\times 4$.

Stricklandia lens (J. de C. Sowerby).

- » 10. Dorsal aspect of the exterior of specimen S. M. C. A. 13 518; original from zone 6 c α , Malmøy. $\times 1\frac{1}{5}$.
- » 11. Anterior aspect of the same specimen. The spondylium curves dorsally towards the lamellar brachial-processes. $\times 1\frac{1}{2}$. Cf. text-fig. 21.
- » 12. Dorsal aspect of the ventral valve of the same specimen, showing the short, broad spondylium. $\times 1\frac{1}{4}$ approx. Cf. text-fig. 21.
- » 13. Ventral aspect of the dorsal valve of the same specimen. The inner-plates are attached to the posterior portions of the brachial-processes. $\times 1\frac{1}{4}$ approx.
- » 14. Ventro-lateral aspect of a dorsal valve. $\times 2$. S. M. C. A. 13 517; original from zone 6, Asker.
- » 15&16. Dorsal and dorso-lateral aspects of the ventral valve of the same specimen, showing the spondylium and short, supporting septum. Fig. 15 $\times 2$; fig. 16 $\times 2\frac{1}{2}$.
- » 17. Anterior aspect. The spondylium, supported on a short septum, curves dorsally towards the brachial-processes. $\times 2$. S. M. C. A. 13 516; original from zone 6 b β , Asker. Compare text-fig. 20.
- » 18. Anterior aspect of specimen S. M. C. A. 13 517. $\times 2$.
- » 19. Dorsal aspect of the exterior of specimen S. M. C. A. 13 516. $\times 2$.



NORSK GEOLOGISK FORENINGS VIRKSOMHET

MØTE TORSDAG 2. DESEMBER 1937

Tilstede 27 medlemmer og 20 gjester.

Til revisor blev gjenvalgt H. H. SMITH og J. HELVERSCHOU.

Cand. real. EINAR JENSEN: *Eksperimentelle bidrag til kjennskapet om de sølvførende ganger på Kongsberg.*

Vil senere bli trykt i tidsskriftet.

Efter foredraget uttalte sig A. Holmsen, S. Foslie, S. Føyn og foredragsholderen.

Konservator H. ROSENDAHL: *Rembesdalsskåki og Demmevatn på Hardangerjøkulen.*

Trykt i Naturen 62, 1938 p. 1—19.

I anledning foredraget uttalte sig A. Holmsen, som henviste til en avhandling under trykning i Norsk geografisk tidsskrift: „En isdemt sjø i Norge i nutiden“, videre uttalte sig G. Holmsen, H. Rosendahl, F. Isachsen, K. Münster-Strøm, O. Rogstad.

G. HOLMSEN: I høst hadde jeg den fornøielse å delta i en befaringsreise av Demmevatnets tørrlagte bunn og av Simadalen sammen med generaldirektør Rogstad og ingeniør Solem fra Norges vassdrags- og elektrisitetsvesen. Vi iakttok et sunket parti av breveggen som stuper op Demmevatnet. Overflaten av breen viste en traugformig senkning som vi antok fremkommet ved at isen hadde satt sig efter vatnets tømning, og efter vår mening hadde dette parti før katastrofen flytt i vatnet. Under denne flytende eller utoverhengende del av breen tenker vi oss at flommen har brutt sig vei til ferdige breeløp i Rembesdalskåkje.

For vassdragsvesenets forebyggende arbeider er det av betydning å kjenne til hvordan breen har vokset eller minnet ned gjennom tidene. Av Rembesdalskåkje fins der systematiske målinger bare for de to siste år og for årene 1918 til 1921. De målinger som i sin tid blev iverksatt av P. A. Øyen for Jotunheimbreens vedkommende og av J. Rekstad for Vestlandets breer og Svartisen begynte først ved århundreskiftet. Vi kan derfor heller ikke ved å sammenligne med andre breer komme noen vei med erkjennelsen av Rembesdalskåkjens variasjoner i tiden før tunnelen blev bygget.

Rekstads målinger blev hele tiden bekostet av Bergens museum. Rekstads arbeide er nu overtatt av dr. Fægri, som hvert år offentliggjør resultatene i Bergens museums årbok. Foruten disse målinger er der med bidrag fra fond, av A. Hoel og W. Werenskiold iverksatt målinger i Jotunheimen for å registrere breenes forandring. Flomkatastrofen i Simadalen viser at bremålinger har øieblikkelig praktisk betydning foruten den mere langsiktige gjennom å utvide vårt kjennskap til klimaoscillasjonene. Det er derfor å håpe at målingene så vel av breenes beliggenhet som hoidemålinger av breenes overflate i samme profiler vil kontinuerlig fortsettes.

Cand. mag. AAGE KJELLERØD: *En skjellbanke under raet i Østfold.*

Foredragsholderen meddelte at han i et par somrer hadde holdt på med kartlegging av de løse avleiringer innen kartbladet Sarpsborg. Det som hadde interessert ham mest var kartleggingen av østraet. Dette var nu inntegnet fra Idd og til grensen mellom Råde og Rygge.

Ca. 7 km nordenfor Sarpsborg, i Kalnes grustak, hadde han støtt på en skjellbanke, som efter foredragsholderens mening lå under raet. Dessverre var det så sent på høsten, da dette fund blev gjort, at sneen kom for han kunde gjennomføre en systematisk undersøkelse. Men han mente å gjennomføre denne sommeren 1938, slik at han kunde komme med en redgjørelse for dette i Norsk geologisk tidsskrift.

Grustaket er tatt op slik at en får et godt snitt langsefter midten av raet. Det støter i syd inn til en opstikkende kolle som heter Brattåsen 121 m o. h. Grusen faller av i raets retning, som her er nordlig. Det nevnte snitt er ca. 110 m langt, og 10 til 11 m dypt. Profiliet består øverst av et lag strandgrus med en mektighet på 1—1,5 m. Like under sees en diskordans mellom det utvaskede strandgrus og lagene i det skråttstillede ragrus, delvis markert ved et rullestenslag. Ragrusets skrå stilling minner om en deltadannelse. Ragruset hviler underst på finsand.

I bunnen av grustaket ligger mytilusbanken. Her er det mytilus edulis og balanus crenatus i mengde. Dessuten forekom cyprina islandica i store hele eksemplarer, med godt bevart epidermis. Innerst i grustaket, under de eldste gruslagene blev funnet lucina borealis i mengde.

Under mytilusskiktet var et lag med sandholdig leire ca. 75 cm—1 m. med lucina borealis, cardium echinatum, cardium minimum, abra alba, pecten septemradiatus etc. Skjellbanken ligger ca. 90 m o. h. Da skjellene var så godt bevart i hele eksemplarer, må de være på primært leiested, de skulde da være avsatt under en tid med marin grense på 100—110 m, som her svarer til ca. 36 % av stigningen; dette svarer til Øyens pholas-nivå.

I faunistisk henseende er det også en ganske god overensstemmelse. Det mest nærliggende blir altså å plasere funnet til nevnte nivå. Det som nu er problemet er hvordan dette mektige lag av skråttstillet ragrus, med fallretning langs raet, og som dekker skjellbanken, er dannet.

Hadde skjellbanken ligget på proksimal- eller distalkanten, under det skiftede ragrus, så hadde det hele vært liketil. Det mest nærliggende

er vel å tenke sig at det på Brattåsen, som raet støter op til i syd, har vært ophøpet store grusmasser, som under landets stiging er vasket utover og som har begravet den fauna som levet her på skråningen.

Tanner har i 1930 foretatt en sammenligning mellom sine nivåer og Øyens. Diagrammet viser at grensen for pholas-nivået og d-linjen faller sammen. Nu har Asklund i 1935 i to avhandlinger fremhevet muligheten for at d-linjen muligens er gotiglasial.

Foredragsholderen mente nu, på grunn av sitt kjennskap til det ytre raet og østraet, som en antakelig arbeidshypotese under de fortsatte undersøkelser, at den før nevnte skjellbanke muligens hørte til den gotiglasiale tids klimatoptimum, idet han mente at dette falt mellom de to raers dannelse, og at østraet var grensen for ratidens bre.

Efter foredraget uttalte sig H. Rosendahl, K. O. Bjørlykke, G. Holmsen, A. L. Rosenlund, F. Isachsen, T. Strand.

H. ROSENDAHL: Raets innside er alle steder, hvor en kan se snitt i grustak, oppbygget på samme måte som i grustaket på Kalnes, nemlig av strandgrus i mektige lag ovenpå hverandre. Det må naturligvis være avsatt etterat isfronten var smeltet bort. At strandabrasjonen er den generelle årsak til denne avsetning av materiale, er naturlig å tenke sig. Det vilde være ikke bare en søkt og kunstig, men en umulig og ubrukt forklaring, at elver hadde munnet overalt langs raets innside. Setter man sig inn i situasjonen i den tiden, da raet dukket op over havnivået, skulde dette være klart. Således var raet ved Brattåsen på Kalnes i den tiden, det her er tale om, nemlig ved en havstand på ca. 110 m og nedover, en langstrakt holme av løsmateriale støttet til fast fjell på syd-siden, som Jomfruland i våre dager.

Spørsmålet om elver har vært medvirkende til akkumulasjonen av dette materiale spiller for øvrig ingen rolle for vårt egentlige problem. Hovedsaken er jo at materialet er utskylt fra de nærmeste omgivelser og avsatt i stranden.

Strandgruset på Kalnes har en spesiell interesse ved å inneholde skjell. Men som skjellbanke betraktet skiller den sig ikke i nogen vesentlige trekk ut fra våre andre skjellbanker. At den i dette tilfelle har raet til underlag gir oss ikke grunn til nogen annen synsmåte enn den vanlige. Når foredragsholderen har kalt sitt foredrag „En skjellbanke under raet“, er det ikke rett. Skjellbanken er ikke dekket av annet materiale enn det som er sekundært avsatt på raet, etterat isen var borte. Det vilde derfor ha vært korrekt å kalle foredraget „En skjellbanke på raet“.

Som ved alle andre skjellbanker melder også her problemet sig: Hører fossilene biologisk til i strandavleiringen eller er de sammen med eldre fossilførende materiale avsatt sekundært? Slik som denne skjellbanken ligger, er dette spørsmålet særlig viktig. På grunn av beliggenheten i den øvre del av raet kan den nemlig ikke være utvasket fra eldre, høiere liggende skjellbanker. Hvis den er avsatt sekundært, må den derfor skrive sig fra materiale i raet, altså eldre enn raet.

At skjellbankens fossilinnhold ikke kan være utvasket fra eldre postglasiale banker sier også den faunistiske sammensetning. De to mest varmekjære former, *Lucina borealis* og *Thracia papyracea*, kan vi neppe vente å finne i eldre postglasiale avsetninger, når vi for Kalnesbanken regner strandlinjen til 110 m, svarende til Pholas-nivået eller 36 % stiging av landet fra den marine grense som er 175 m o. h. Riktignok er *Ostrea edulis* på Borge i Skoger funnet op til 20 % under den marine grense, svarende til Littorina-nivået, så det skulde ikke være utelukket at også *Lucina borealis* og *Thracia papyracea* på gunstige lokaliteter skulde kunne finnes høiere. Men i almindelighet vil Pholas-nivået være øvre grense for alle disse fossiler.

Den eneste mulighet for å fortolke skjellbanken som en sekundær avsetning er altså at den skriver sig fra raets eget materiale. Mot denne fortolkning tyder fossilenes gode opbevaring. De tynne, skjøre skall av *Thracia papyracea* er ennu hele, og *Lucina borealis* ligger med høire og venstre skall sammen som hos det levende dyr. Man kan vanskelig tenke sig at disse skall først har vært transportert av isen og ligget utsatt for breens trykk på raets innside og derefter utvasket av bølgene. Skjell, som ligger inne i morene, er gjerne helt opknust.

Til slutt må man være opmerksom på det viktige faktum, som allerede før er nevnt, at ingen av fossilene ligger inne i det primære ra-materiale, men bare i det sekundært utvaskede strandgrus.

Inntil noget annet blir bevist, er det ingen grunn til å anse skjellforekomsten på Kalnes som annet enn en almindelig postglasial skjellbanke, for det vesentlige liggende på sitt primære avleiringssted.

K. O. BJØRLYKKE vilde få lov å minne om raenes historie. Den begynner med professor Keilhau, som i 1834—36 foretok sin reise sammen med lektor Boeck for å studere landjordens stiging. Han omtaler raene og om deres kontakt med det marine leir ved Glæng i nærheten av Sarpsborg uttaler han: „det synes at det marine ler er alveiret paa begge affald av banken og at det saaledes optræder som en uavhengig, bestemt nyere avsætning.“ Til den samme opfatning kom også Kjerulf, som efter Rekstads oplysning i „En Mytilusfauna under morénemasser i Smaalenene“ (N. G. U. aarbok for 1912) i 1858 sendte to assistenter til Østfold for å kartlegge de kvartære avleiringer. De kom begge til det resultat at morenene lå delvis over leirlagene. Kjerulf fant at arbeidet ikke var utført efter avtale og avskjediget assistentene. Jeg har selv i „Litt om Aasmorenen“ (Tidsskr. for det norske landbruk 1900) og i „Om raenes bygning“ (N. G. U. aarbok for 1905) vært inne på den tanke at marine leirlag var innpresset og begravet under morenemassene i raene på grunn av fremrykking av innlandsisen.

Da jeg dog fremdeles var litt i tvil om dette forhold ved Åsmorenen fikk jeg i 1906 foretatt en utgraving av en grøft fra arcaleret opover mot morenens topp, beskrevet i „Havler og morene“ (Norsk geol. tidsskr., b. III, 1914) og demonstrert for medlemmer av Norsk geologisk forening den 24. mai 1906). Det viste sig i denne grøft med stor tydelighet at

at arcaleret kilte ut opover mot toppen av morenen, og at det over leret liggende sand og grus var av postglasial alder utvasket fra morenen. Som et nytt eksempel kan jeg henwise til et grustak nord for N. Gjulem i Rakkestad, Østfold, som er både tegnet og fotografert i „Jordarter og jordsmonn i Østfold fylke“ (Skr. Vid.-akad. Oslo 1933, side 25 og 89). Her har man en kjerne av ekte morene, hvortil der på sydsiden slutter sig underst utvasket sand og grus, derover et skivet lagdelt ler (sannsynligvis portlandialer) og derover igjen utvasket sand og grus; de tre sistnevnte lag kiler ut på morenens sydside opover mot morenens topp. Raene i Østfold består dels av en indre ekte morenekjerne, men dessuten for en stor — eller største del — av utvasket og oftest lagdelt morenemateriale, som har vært omleiret og avsatt i vann dels av breelver og dels av bølger, kanskje i de fleste tilfelle av havbølgene under landets stigning og da til dels også førende sen- eller postglasiale skjell. På østlandet er hittil ikke påvist sikre avleiringer fra forskjellige istider eller interglasiale avleiringer. Men forholdene er annerledes på Jæren, hvor man har to forskjellige slags morener, de eldre avsatt av en Skageraksbre med knuste havskjell og kritt- og flintstykker fra Skageraks bunn og de yngre morener avsatt fra en bre fra det indre av landet. Mellem disse to morener kan det forekomme interglasiale rester med en temperert fauna (ved Reve).

Om forholdet i grustaket ved Kalnes skal jeg ikke uttale mig, da jeg ikke har vært der i de senere år. Det kommer vel mest an på tolkningen av forholdene eller observasjonene. Men har man satt sig inn i raenes historie eller tolkning gjennom årene minnes man det latinske ordsprog: *Vestigia terrent*, ɔ: sporene avskrekker. Det første inntrykk er, særlig hos nybegynnere, at skjellførende ler eller sand med en mere eller mindre temperert fauna ligger tydelig begravet under morenegrus, til dels med blokker, men nærmere undersøkelser har vist at morenegruset er omleiret eller utvasket fra morenens topp og altså er av yngre alder enn de fossilførende ler- eller sandlag, som gjerne kiler ut opover mot den ekte morenekjerne.

Jeg kunde tilføie at det er fristende å komme med nye opdagelser eller formodninger, og det er heller ingen videre risiko ved det; men det er efter min erfaring farligere å komme med innvendinger og beriktigelser. Det blir som oftest optatt unådig. Det var iallfall tilfelle da jeg tillot mig å kritisere og beriktige Rekstads opsats: „En mytilusfauna under morenemasser i Smaalenene“ (N. G. U. aarbok for 1912). Rekstads voldsomme utfall i den anledning kan man lese i Norsk geol. tidsskr., b. III. Men jeg tror nok at en mytilusfauna under morenemasser i Østfold er forsvunnet fra den geologiske litteratur siden den tid.

G. HOLMSEN: Til K. O. Bjørlykkes innlegg kan bemerkes at raets indre så langt fra alltid består av morenegrus at det tvert imot almindeligvis er bygget av ler. I litteraturen har lerkjernen vært omtalt som en av breen sammenskjøvet eldre avsetning. La oss nu legge til side de på forskjellig vis tolkede snitt gjennom de indre raer (Svelvik-Åsmorenen til Grefsen-morenen) og holde oss til snittet i Kalnes grustak. Her er

raet skåret tvers gjennom under grusdriften, men driften går ikke i dypet fordi materialet nedad blir for finkornig. Det er derfor ingen utsikt til å finne noen kjerne av bregrus her heller.

Det snitt foredragsholderen omtalte av den grusvegg jeg har opnådd en foreløpig fredning av, er over 110 m langt og viser et ensrettet nordlig fall av gruslagene, det vil her si omtrent i raets lengderetning. Snittet når helt inn mot raets midtakse. Nær innunder det høieste av raet, så langt inn som driften hittil har nådd, finner vi en fauna bl. a. med en såpass varmtelskende art som *Lucina borealis* i mengde. Dette er meget bemerkelsesverdig fordi den skjellførende sand vi ser nær innunder raets rygg og som sannsynligvis vil kunne følges videre ettersom grusdriften blotter den, ifølge lagstillingen må være eldre enn samtlige de skrått-stillede lag over den som tilsammen utgjør grustakets 110 m lange grusvegg.

Det er vanskelig å tenke sig denne svære lagrekke oplagt av undervannsdønning, som av H. Rosendahl fremhevet, uten fornyet tilførsel av bregrus. Jeg kan imidlertid ikke innse hvad der er til hinder for å anta at de skråttstillede gruslag i snittet er avsatt i sjøen ennå mens breen stod eller fløt her og stadig avgav nytt grusmateriale.

Nogen grense mellom de skjellførende sandlag og ragruset kan ikke sees. Skjellmulder øverst i skjellbanken tyder imidlertid på at dens øverste lag er omleiret.

Efter mitt første besøk på stedet hvorunder jeg kun fant små mytilus, cyprina, balanrester etc. tenkte jeg mig at banken kanskje kunde være en littoralfacies av yoldialeret. De lucitanske arter som senere blev funnet av Kjellerød under mytilussanden, *Lucina borealis*, *Cardium echinatum*, *Abra alba* m. fl. er ikke forenlig med denne opfatning, men viser, om jeg har tydet stratigrafien riktig, at banken er av en interglasial alder.

LOV FOR NORSK GEOLOGISK FORENING

(Efter lovforandring i februar—mars 1938.)

§ 1. Norsk geologisk forenings opgave er å bidra til utvikling av geologisk kunnskap i teoretisk og praktisk retning. Foreningen vil arbeide for dette ved møter med diskusjon og om mulig også på andre måter. Foreningen utgir et geologisk tidsskrift.

§ 2. Foreningen har et styre bestående av formann, sekretær, redaktør og to andre medlemmer samt en varamann.

Styret kan, om det måtte finne det påkrevet, ansette en lønnet regnskapsfører for et år om gangen. Lønningen må godkjennes av generalforsamlingen.

§ 3. Formannen sammenkaller og leder foreningens møter. I tilfelle av forfall fungerer som stedfortreder et av styrets øvrige medlemmer.

§ 4. Formannen og sekretæren forvalter foreningens midler.

§ 5. Foreningens tidsskrift, Norsk geologisk tidsskrift, redigeres av styret med den valgte redaktør som hovedredaktør. Det utsendes såvidt mulig regelmessig med 4 hefter om året.

§ 6. Foreningen holder generalforsamling hvert år innen utgangen av februar måned. Det holdes hvert år 6 ordinære møter på en av styret fastsatt dag i månedene februar, mars, april, mai, november og desember.

§ 7. Sekretæren har i generalforsamlingen å fremlegge beretning for det foregående år og regnskapet i revidert stand.

På generalforsamlingen velges styre og 2 revisorer med varamenn for det kommende år. Den samme formann kan ikke velges mer enn 2 år på rad.

Valget av styre foregår således: Først velges formann, sekretær og redaktør særskilt. Derefter velges 3 andre medlemmer: de to, som har flest stemmer, blir styremedlemmer, den tredje blir varamann.

Skriftlig avstemning brukes ved valg av styret, og hvis noget medlem fremsetter krav derom, også ved andre avgjørelser. I tilfelle av stemmelikhet avgjøres valget ved loddtrekning.

§ 8. Medlemskontingenten er 10 kr. pr. år. Man kan bli medlem for livstid ved å innbetale 100 kr. en gang for alle eller 30 kr. pr. år i 4 år i trekk. Dog kan medlemmer, som har betalt kontingent i minst 20 år, søke styret om å bli livsvarig medlem ved å innbetale 50 kr., og medlemmer, som har betalt i 15 år, ved innbetaling av 75 kr. Kontingenten for de livsvarige medlemmer opbevares som et fond, hvis midler styret i samråd med revisorene anbringer i gode rentebærende papirer. Styret treffer bestemmelse om bruken av fondets renter.

§ 9. Forslag om å opta nye medlemmer innsendes til styret og må være undertegnet av 2 medlemmer. Styret forelegger på førstkommande ordinære møte forslaget for foreningen, som treffer avgjørelse om innvalget. For innvalg kreves minst $\frac{2}{3}$ av de avgitte stemmer. Efter forslag av styret kan geologer utenfor Skandinavia innvelges som foreningens korresponderende medlemmer.

§ 10. Forslag til forandring i foreningens lover behandles og avgjøres i generalforsamlingen, når forslaget er kunngjort for medlemmene minst 10 dager forut. Ved avstemningen utkreves $\frac{2}{3}$ av de avgitte stemmer for at beslutningen kan være lov. Forslagene vedtas eller forkastes punktvis.

STATUTTER FOR NORSK GEOLOGISK FORENINGS REUSCH-MEDALJE

1. Reusch-medaljen er opprettet av Norsk geologisk forening til minne om dr. Hans Reusch. Dr. Reusch tok initiativet til å stifte foreningen, var dens første formann og viste den siden en stadig varm interesse. Han grunnla også foreningens tidsskrift og støttet det på mange måter.
2. Medaljen har en klasse og preges i bronse.
3. Medaljen utdeles til yngre forfattere som påskjønnelse for en avhandling. Den kan bare utdeles en gang til samme person.

En avhandling må for å komme i betraktning opfylle følgende betingelser:

- a) Den må behandle emner innen geologien eller dens forskjellige hjelpevitenskaper og må angå norske forhold.
 - b) Den må være bygget på omhyggelige iakttagelser eller grundige teoretiske betraktninger og må inneholde nye og verdifulle bidrag til de emner som behandles. Dessuten må den være fremstillet i en klar og konsis form.
 - c) Den må ha ligget ferdigtrykt i minst 1 år og ikke over 5 år regnet fra datoen for utdelingen.
4. Medaljen utdeles av foreningens styre efter forslag av en komité bestående av foreningens formann og to medlemmer utenfor styret; de velges hvert år på generalforsamlingen og kan ikke velges to år i trekk. Motivert forslag skal innsendes skriftlig og må være styret i hende senest tre måneder før utdelingen. Hvis et forslag forkastes skal grunnen til forkastelsen meddeles forslagskomiteen i en skrivelse undertegnet av alle styremedlemmene. En besluttet utdeling skal foregå på første årlige generalforsamling efter beslutningen, og motiveringen skal refereres på generalforsamlingen. Det kan ikke utdeles mere enn en medalje hver gang undtaket i tilfelle av, at den belønnede avhandling har to eller flere forfattere, da hver av forfatterne får en medalje. Medaljevinneren får foruten medaljen også et enkelt diplom undertegnet av alle styremedlemmene.
5. Såfremt de fornødne midler kan skaffes til veie uten innskrenkning av foreningens almindelige virksomhet, kan medaljen ledsages av en pengebelønning, hvis størrelse fastsettes av styret for hver gang.

STATUTTER FOR SULITELMAFONDET TIL FREMME AV NORSK GEOLOGISK FORSKING

(Stadfestet av Socialdepartementet 7/II 1930)

§ 1. „Sulitelmafondet“ er stiftet av Sulitelma Aktiebolag den 30. mai 1916 til minne om Sulitelma-grubenes grunnleggelse ved konsul N. Persson og i anledning av bolagets 25-årige virksomhet.

Fondets grunnkapital utgjøres av nevnte bolags gave, i 1916 nominelt kr. 20 000,00 av bolagets 5 1/2 % obligasjoner (av dets obligasjonslån av 1. juni 1915 på 3 000 000 kroner), i 1917 10 000 og i 1918 20 000 svenske kroner, samt gave i 1918 fra konsul Ivar Persson Henning, stor 5 000 svenske kroner.

I året 1930 blev fondet sluttet sammen med det med Fridtjof Nansens fond forbundne „Fond til fremme av norsk geologisk forskning“ („Det geologiske fond“), stiftet i 1916 ved en gave av kr. 10 000,00 fra dr. H. H. Reusch og en rekke mindre gaver, mest fra forskjellige norske gruber og verk.

I året 1932 blev fondet videre sluttet sammen med det med Fridtjof Nansens fond forbundne „Det amerikanske fond“, stiftet i 1904 ved en gave av dr. H. H. Reusch, stor kr. 6 000,00, representerende hans honorar for en rekke geologiske forelesninger holdt i 1898 ved Harvard-universitetet i Cambridge i De Forente Stater.

Fondenes kapital ved sammenslutningen var: Sulitelmafondet kr. 63 206,⁶⁶. Det geologiske fond kr. 41 570,⁶³ og det amerikanske fond kr. 6 878,⁴¹.

§ 2. Fondet skal danne et eget selvstendig fond, ved felles styre forbundet med „Fridtjof Nansens fond til vitenskapens fremme“, og forvaltes og bestyres efter samme regel som for dette fond bestemt.

§ 3. Fondets kapital må ikke røres og skal anbringes således som for offentlige stiftelsers og legaters midler til enhver tid bestemt; den skal økes ved avsetning av minst $\frac{1}{10}$ av den årlige renteavkastning og kan for øvrig økes ved gaver og eventuelle innskudd på annen måte.

§ 4. Fondets renter for øvrig skal brukes til fremme av norsk geologisk forskning på alle måter, som fondets styre til enhver tid finner best.

Inntil halvdelen av den disponible renteavkastning kan brukes til å utgi geologiske publikasjoner.

§ 5. Fondets styre fattet hvert år beslutning om bruken av den disponible renteavkastning efter innstilling av et sakkyndig råd, bestående av 4 medlemmer, 2 valgt av Det norske videnskaps-akademi i Oslo og 2 valgt av Norsk geologisk forening.

Rådets medlemmer velges av de nevnte institusjoner i desember måned for de 3 næstfølgende kalenderår.

Styret kan ikke fravike det sakkyndige råds innstilling, men kan sende den tilbake til rådet til fornyet behandling, om det finner noget å bemerke.

§ 6. Når fondets styre ved den årlige utdeling måtte finne avgjørende grunner til enten delvis eller i sin helhet ikke å bruke den disponible del av renten, kan denne helt eller delvis opspares for bruk et senere år.

§ 7. Efterat fondets statutter er stadfestet av Sosialdepartementet skal disse ikke kunne forandres uten samtykke av Det norske videnskaps-akademi i Oslo, Norsk geologisk forening og vedkommende departement.

§ 8. Særskilt beretning om fondets virksomhet skal hvert år offentliggjøres i forbindelse med offentliggjørelsen av beretningen om Nansen-fondets virksomhet. For øvrig er fondet undergitt samme kontroll og regnskapsrevisjon som „Fridtjof Nansens fond“.

MEDLEMSLISTE

ved generalforsamlingen 3. februar 1938.

*: livsvarig medlem.

Tallet i parentes er innvalgsåret.

(S): stifter (18. februar 1905).

Æresmedlem:

Brøgger, W. C., professor. Bekkelaget pr. Oslo. (S).

-
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73 årsbetalende medlemmer.

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